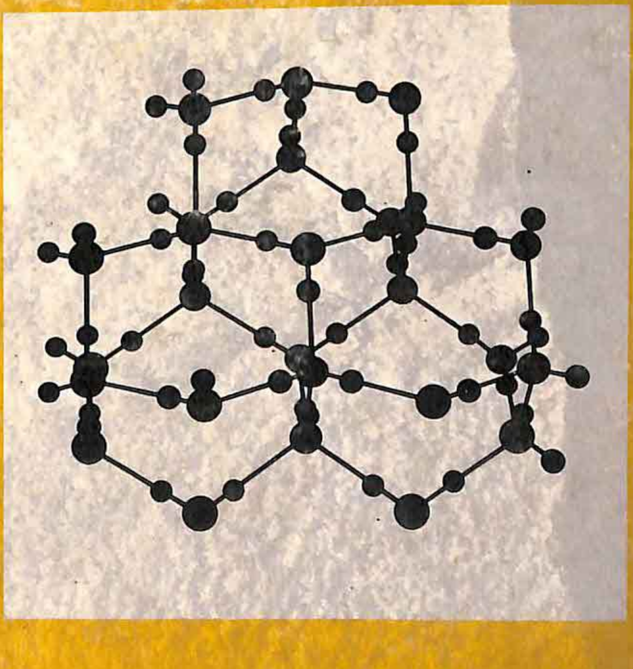
New trends in chemistry teaching

Volume IV

Chemistry

The teaching of basic sciences



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New trends in chemistry teaching

Volume IV

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at the International Congress on the Improvement
of Chemical Education held in Wrocław, Poland,
17-22 September 1973

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Preface

Within Unesco's programme to foster the improvement of science education at all levels, the promotion of the international exchange of ideas and information plays an important role. One of the means of achieving this exchange has been the publication of a series on *The Teaching of Basic Sciences.* For each of the individual sciences of mathematics, physics, chemistry and biology, as well as for integrated science, there have been two or more volumes entitled "New Trends in the Teaching of...". These volumes were intended for all those concerned with improvements in the teaching of the science in question – teachers in universities and teacher training institutions, officials of ministries of education, secondary school teachers, students preparing to be science teachers, members of examination boards, school inspectors, science teachers' associations, etc.

In the past, the objective had been to publish one such volume in each field every two years. Each volume contained materials in more than one language – mostly English with some French. These volumes did not contain an analysis of trends but mainly consisted of a mixture of reprinted materials (e.g., summary report of important seminars and conferences, articles from leading journals), original articles and supplementary factual information.

Although all volumes in the various fields have been well received it would seem even more useful and valuable : (a) to publish volumes containing actual analyses of trends and problems in various aspects of education in the science involved, as revealed by detailed analyses of the recent relevant literature ; (b) to print separate language versions of each publication (at least English, French and Spanish) ; and (c) to issue these publications in each discipline at the rate of one every four or five years. Volume IV of *New Trends in Chemistry Teaching* has been prepared in accordance with this new policy and therefore differs in content, but not in purpose, from the preceding three volumes in the set.

As a first step in preparing this publication, the overall subject of the improvement of chemical education was tentatively divided into a number of topic areas which, taken together, covered all major aspects of chemical education. In collaboration with the Committee on the Teaching of Chemistry of the International Union of Pure and Applied Chemistry (IUPAC), its National Representatives and other leading specialists in chemical education, Unesco then produced a preliminary bibliography of the recent literature throughout the world on the improvement of chemical education. On the basis of this bibliography, and in consultation with the above-mentioned organization and specialists, a final decision was made on the topics of trend papers, each paper being intended to give an overall view of the trends and problems in a specific area of the general subject.

In collaboration with IUPAC, the Polish Academy of Sciences, the Polish National Commission and the Polish Ministry of Science, Higher Education and Technology, Unesco next organized an International Congress on the Improvement of Chemical Education, held in Wroclaw (Poland) 17-22 September 1973, the purposes of which were : (a) to identify and analyse the present problems and recent trends (especially over the last four years) in chemical education at all levels, within and outside the formal educational system ; (b) in the light of this analysis, to outline a proposed four-year co-operative plan of action – among international, regional and national organizations – for the further improvement of chemical education ; (c) as a means of disseminating widely the analysis of the problems and the proposed solutions, to prepare material for Volume IV of *New Trends in Chemistry Teaching.*

Thirteen trend papers were prepared and subsequently revised by their authors in the light of the ideas and suggestions which arose during discussions in the relevant working groups. The resulting papers, which constitute the thirteen chapters of the present volume, therefore represent the integrated knowledge and experience not only of the individual authors but also of the international experts who participated in the congress. Furthermore, the individual working groups were asked to suggest practical action which should be undertaken by various bodies – national, regional and international – for the solution of existing problems. The various action plans were synthesized into a single set of recommendations which, modified in the light of discussion at the closing plenary session, constitute the final section of the present volume.

Special acknowledgement is made to all authors of the chapters of this volume and to the editor, Dr Peter Farago (United Kingdom) who also served as the rapporteur of the congress. The opinions expressed in this publication are the responsibility of the authors and the editor. Furthermore, the designations employed and the presentation of the material do not imply the expression of any opinion whatsoever on the part of Unesco concerning the legal status of any country or territory, or of its authorities, or concerning the delimitations of the frontiers of any country or territory.

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I. Factors affecting the design of chemistry courses and programmes

The changing needs and views of society

by C. Terlon

INTRODUCTION

The new trends in chemistry teaching can be identified by selecting the best articles from the relevant literature - those which give evidence of the changes in content and in the methods used to teach this subject - and by reflecting on the external as well as internal factors which influence the chemistry syllabus. It is now becoming accepted that these factors must be taken into consideration, either with a view to mitigating their effects or, on the contrary, with a view to adapting chemistry teaching more closely to the needs and motivation of the students, and, more generally, making it correspond more closely with what societies have a right to expect from their educational systems.

This Paper is intended as a contribution to reflections on the changes in society which must inevitably have repercussions on the design of curricula, particularly as a new awareness of the links between science and society has led to a new approach to these problems.

Until the beginning of the sixties, science and technology developed against a background of confidence in the effectiveness of science, and the political prestige of scientists, particularly in the United States of America and the United Kingdom, was considerable: for example, ever since the war, scientific institutions and national science policies had been profoundly influenced by the ideas and style of physicists.

During the sixties, economists and systems analysts gradually gained increasing influence over science policies in Europe; national concern with questions ranging from health to general social and economic problems began to dominate the scene. (1)

At the same time a feeling of disenchantment with science began to appear in the United States (2) and was to develop later and in different ways in Europe. So our world is now divided between two conflicting attitudes: recognition of the dynamism of scientific development which, however, is failing to control progress, and at the same time growing indifference by society towards science, an attitude which is in danger of developing into one of rejection.

THE IMAGE OF SCIENCE IN PRESENT DAY SOCIETY

This changing attitude to science mainly concerns the Western countries: in the Eastern countries there is still a powerful interest in science and technology, while the size and urgency of the problems confronting them makes developing countries more interested in using available scientific and technical resources, suitably adapted, to achieve a higher standard of living.

This rough outline of the different possible approaches to science could be further simplified by reducing it to a distinction between two types of approach, that of capitalist society and that of socialist society (at varying stages of development), in that political, economic and educational systems are interdependent.

The new image of science in Western countries

The hope traditionally placed in scientific progress is now giving way to doubt as to the value of science and the benefits of technology; the level of the questions asked varies according to who asks them, the diversity of attitudes reflecting the fact that the societies in question are far from being homogeneous. There is an increasing public wariness of many aspects of science and of technological imperialism. When the general public is asked, 'What has science really done for you?' the answer given is that there have been benefits, examples being chosen mainly from the sphere of medicine, but that, on the other hand, we have had to pay dearly for such benefits in the forms of increasing pollution of the air, water and the land, of an upsetting of the natural equilibrium necessary for the survival of flora and fauna, of more and more artificial food, of more noise, of the atomic bomb, of the fantastic increase in the population, which has risen from 250 million 2,000 years ago to 4,000 million human beings today 'thanks' to progress in hygiene, drugs and fertilizers, etc. (In the Middle Ages, pollution in the towns was appalling but remained limited in space, whereas mercury originating from the waste products of industries thousands of miles away is now found in the Antarctic.)

To this awareness of the harmful consequences of technological progress is now being added an awareness of the fact that we are squandering our natural resources and will probably have to pay the price sooner or later: our civilization might well collapse if we do not control the continuing expansion which makes us impoverish arable land, cover fertile soil with the concrete of our towns and motorways, and destroy our supplies of oxygen by travelling on unnecessary errands through the atmosphere in jets which burn up our reserves of fuel, while the population explosion is as serious a threat to our civilization as nuclear war. (3)

Another source of anxiety which is beginning to emerge is closely bound up with certain modern technological achievements which have created formidable technical instruments constituting a threat to individual privacy, instruments which can be used to obtain and record information that those concerned would like to keep confidential and that can then be stored, and easily and rapidly retrieved when required. This potential threat is made even more serious by the fact that the people affected generally have no means of knowing that this information has been collected or what use is made of it, and are not aware of the fact that they may be under physical observation (by visual and acoustic devices), psychological observation (by means of tests in which the individual reveals his personality without being fully aware of the significance of certain questions) or observation by computer (with the added danger here that information can be easily erased and replaced by other information without any detectable trace of the operation, which was practically impossible with the old-fashioned filing systems). (4)

Public opinion is thus becoming more and more alive to the problems of the environment and, more generally, to the concept of quality of life; but although we are aware that we have reached a stage of development where every need satisfied gives rise to new needs and, for this very reason, problems which had gone unnoticed may suddenly start to cause acute social discontent, this does not automatically lead to plans for alternative solutions: the pollution of the environment, the chaos of urban life and the inadequacy of the university cause dissatisfaction which finds no reflection in any detailed plans for a new type of environment, town, or university which might prove more satisfactory. (1)

This spontaneous expression of concern is more clearly formulated in the Brooks Report (1) which, noting that the general public and the specialists alike, after a period of euphoria, are now feeling somewhat disenchanted and uneasy about science, tries to analyse the reasons for this change in attitude which seems to be due primarily to what might be called misuse of technology and perhaps even of science. The report finds that there have been too many innovations in some sectors and too few in others. This has led to deterioration of the environment and living conditions in big towns and to the proliferation of new technologies which benefit the private consumer but have harmful effects for the community as a whole. Technical progress must be controlled; to this end, science policy should be integrated with other political options, particularly as it is doubtful whether the growth rate of the last hundred years can be maintained. The urgent problem thus raised is the need to use scientific (and technological) resources in a way which corresponds more closely with the requirements of society.

The Brooks Report thus does not go as far as the Meadows Report (5); however some indication of the apprehension with which scientific and technical progress is regarded may be seen in the receptiveness of public opinion to the idea that some limit must be imposed upon growth.

Although in some ways industrialized societies could be said to be approaching saturation point (which means that a decline in growth rates may be expected in a few years' time), it is important to realize that not all classes of society feel equally affected by the 'misdoings' of science: the problem of the environment causes most concern to those classes which are already provided with the material necessities.

Many intellectuals, influenced in particular by Herbert Marcuse, and to a lesser extent by Charles Reich (The Greening of America), reject success and competition in favour of pleasure and self-fulfilment, seeking the liberation of man in a new, post-industrial age. General opinion is more conservative, but some ideas, when taken up by young people, are accepted by the masses, which can also be roused by means of action to defend the environment, action which sometimes succeeds in preventing the development of industrial sites. (5)

Over the last five years scientists have been engaged, in the consideration of two topics expressed in new terms: misuse of science; science seen not as a neutral but as an ideological activity.

According to S. Rose of the Open University (United Kingdom), although analysis of the misuse of science has often been given a political slant to make it appear an inevitable result of scientific activity within the framework of oppressive social order, many scientists nevertheless tend to see it as the manifestation of a relatively autonomous activity: this view leads to a formulation of the problems in terms of individual responsibility. But a countercurrent is now gaining force. Its thesis is that science is not neutral: as an activity organized within the framework of a given social order it reflects the standards and ideology of that social order. It does not exist outside the society which produces it: 'as one social activity among others, bearing the indelible imprint of the society to which it belongs, it reproduces all its features and reflects all its contradictions both in its internal organization and in its applications'. The 'crisis in science' is therefore in fact only one particular aspect of a general crisis; 'the questions which scientists are asking about their rôle in society and the use society makes of their work, are political questions'. (6) It is intrinsic to the nature of science to be a form of power: if science is to be made more democratic it must become politically aware (the problem of self-management in science). This type of analysis is often made by young scientists with 'leftist' sympathies; it is tending to spread and to split the scientific community into two groups, 'science managers' and 'dissenters', as at the international symposium on science and society at St Paul-de-Vence (France) in June 1972. (7)

The importance of this current of criticism should not, however, be overestimated: many of the very scientists who uphold these views tend, when in the laboratory, to forget about the implications of their work and to continue to consider research as self-contained and good in itself.

The uneasiness felt by scientists has its counterpart in the attitude of students in the universities of many Western countries. In denouncing the structure and content of traditional university education for its failure to meet present-day needs, they also denounce the pressures of an economy which wants to step up the efficiency of university training. This invasion of university life by the imperative of efficiency has occurred at the very moment when the disadvantages of economic growth as pursued until now have become clear. The ultimate argument runs thus: 'why work when consumption increases the individual's dependence on material goods and damages man's natural heritage?' (8)

It is possible that 'after mobilizing men, industrial civilization will begin to mobilize women'; this process, which has already started, is similar to that of decolonization in that it will entail value changes. (9) This would seem to be looking well into the future: for the moment, women are becoming aware of their place in a scientific and technical society which has grown up without them. (10)

In the socialist countries

Leonid Brezhnev in his report to the 24th Congress of the Communist Party of the Soviet Union expressed the view that 'one of our major tasks is to speed up decisively the rate of scientific and technical progress', and it would indeed seem that interest and confidence in the power of science and technology is deeply rooted not only in the minds of politicians but at all levels of society. The same enthusiasm for science is still to be found among students, without seeming to raise any questions about inherent risks.

In these countries, education is designed to contribute to the construction of socialist society, and this determines the objectives of the different kinds of education, the content of the education given and the guidance and selection of students, as well as the way in which they work. Thus, for example, the Law on Socialist Education of the German Democratic Republic states (Section 4, Article 52): 'The task of universities and higher educational establishments shall be to train individuals with a socialist outlook and with advanced scientific qualifications who are capable of organizing in a rational manner the application of the latest achievements of science to production, cultural life and other sectors of the socialist society' and (Article 61) 'the objectives of the instruction and education of young scientists shall be determined in accordance with the foreseeable needs of science, the economy and society'.

One characteristic concern which is present at all levels of education in socialist societies is for the moral education of the pupil and later the student, who must be made aware of his own need to work and at the same time of society's need for his work. The teaching methods used to achieve this objective vary, but they all endeavour to establish close links between academic work and socially or economically useful tasks, whilst an extensive system of education by correspondence and evening classes (with reduction of working hours in certain cases) enables an ever-increasing number of workers to obtain a diploma of higher education without interrupting their occupational activities. Certain countries (Cuba, for example) take this one step further: as the level of economic development does not at present enable all to exercise the right to education which is recognized by law (the principle of the right to work is also laid down by law), constant exchanges are organized between students and workers in agriculture and industry to ensure that the latter benefit from the students' knowledge. These exchanges enable the students themselves to learn much from their participation in agricultural or industrial production and also make it possible for workers to attend university, usually on a part-time basis (and to obtain the same diplomas in due course). Thus the problem of expressing the needs of society and taking them into consideration in the educational system is given a completely new aspect since these two terms are in constant, organic interaction. (11)

Furthermore, a very intensive information service is provided, using diversified means to reach various audiences. One of its most original features is that eminent scientists play a leading part in it, supported in their work by teachers and students. There are, for instance, many popular science associations which, with the assistance of university staff, supply information to the general public. In the U.S.S.R., one of the largest of these associations, Znanie (knowledge), has almost 2 million members, has chemical sections in which students assist by preparing lectures under the supervision of experienced teachers, later reading these lectures in factories or schools or to the general public.(12) In the same way, the Mendeleev Chemical Association, in addition to its publications for specialists publishes magazines having very large circulations (Chemistry and Life, The Young Chemist) which help to sustain interest in the discipline and in current progress, while at the same time providing basic information which is suffiently scientific to serve as a springboard for specialized study; this association also organizes courses which begin at a very elementary level and are held after working hours.(13)

In the developing countries

Though it would no doubt be interesting to draw the distinction, as we have done above, between capitalist and socialist societies, one might perhaps start by roughly outlining the different situations emphasizing the common features of the major and particularly urgent problems, the first of which is satisfaction of the basic requirements for food and health (and possibly housing).

Although the leaders of many developing countries recognize that science has a vital rôle to play, a tremendous amount of work still needs to be done to eradicate deep-rooted prejudices and to convince the population that science is not only theory but a means of intellectual and social transformation. In some countries where feudalism is a thing of the not-so-distant past, manual work is despised and technicians do not occupy a very high position in society; few therefore aspire to be technicians, and those who hope to follow a course of higher education prefer the fundamental sciences to their technical applications.(14)

In many African States which became independent in the sixties, the government was quick to lay down a strategy for development to ensure economic and social progress. Development was very often seen as a linear process of catching up with industrialized countries by massive importation of existing technologies. These, however, come from industrialized countries, in which the tendency is to optimize economic profitability in circumstances where capital is more readily available than labour; the opposite is true in Africa, where there is a surplus of labour and capital is scarce. What is needed, therefore, is a technology which is adapted to the special conditions of developing countries rather than a transfer of existing technologies. (15)

A similar situation has developed in education: it was often thought that economic backwardness could be remedied by adopting the school system of the industrialized countries, which is why many towns in the Third World are full of young unemployed who can read and write and who sometimes have diplomas of secondary education.(16)

In short, although it is difficult to deny that the scientific and technical progress achieved in industrialized countries has given the developing countries considerable opportunity to increase their production, it is equally clear that it has been responsible for certain economic imbalances in these countries.

The Brooks Report (1) identifies two factors which have caused this situation: underdevelopment itself, which is a major obstacle to the application of science and technology in developing countries, and the present organization of international economic relations, based on a market the rules of which are to a large extent, whether deliberately or otherwise, determined by the more advanced countries to their own advantage.

It would perhaps be helpful to give some examples. Research into the production and improvement of margarine has made it possible to considerably increase demand for certain products such as coconuts, palm oil and ground nuts; research undertaken in response to the problems of developing countries has led to the discovery of high-cropping varieties of rice and wheat (these discoveries may be considered as marking the beginning of the green revolution in a number of countries).(17) On the other hand, the Secretariat of the United Nations Conference for Trade and Development has calculated that, while world consumption of cotton increased by 1 per cent between 1960 and 1964, consumption of synthetic fibres increased by 50 per cent and that the proportion of synthetic rubber in relation to total rubber consumption increased from 0.6 per cent in 1938 to 56 per cent in 1965.

Thus the belief, prevalent in the sixties, that science could help the countries of the Third World to develop their potential has given way to the view that science has if anything widened the gap between rich and poor countries still further.

An important omission in the above description has no doubt been noticed: that of the People's Republic of China. Although there is an abundance of ideological literature, detailed information on scientific and technical development in China during and after the Cultural Revolution is still hard to come by and gives only a fragmentary picture of the original approaches and solutions adopted by China in this domain. (18)

THE CONSEQUENCES: SOCIETY'S REQUIREMENTS AND THE SOCIAL RESPONSIBILITY OF SCIENCE

Although the impact of science on society has for a long time been self-evident, its counterpart, the growing demand that research and its applications should serve society, is a new phenomenon with far-reaching consequences. If there are to be new forms of interaction between science and society each must improve its information about the other.

The needs of society

Let us first note that there is more than one view of what is meant by the needs of society, for this term may denote the overall requirements of a country, defined in terms of national policies, or the requirements of individuals.

The needs of society which concern us here are those which relate to the educational system and, more particularly, the teaching of chemistry.

If one accepts, with Edgar Faure (19), that 'command of scientific thought and language has become as indispensable to the average man as command of other means of thought and expression' and that science not only enables individuals to master natural forces as well as production processes but is also a decisive factor in the moulding of character, one must consider that it is a priority objective of education to give a sufficiently general scientific training to enable all to become fully responsible citizens.

As far as curricula are concerned, it will therefore be important to bear in mind that if chemistry is to be taught to as many as possible, given its formative value and its importance in the scientific and technical world in which we live, it must be remembered when teaching it that those for whom the curricula are intended will not all become chemists but will, on the other hand, all be required to be well-informed citizens, engineers included. This is why the content of chemistry lessons and the teaching methods used are important and should not be approached only from the point of view of progress achieved in the subject. There seems to be a large measure of agreement at present on the need to teach chemistry as a subject integrated into a multidisciplinary framework, to be considered from the point of view of man and not as an abstract exercise cut off from life. (2) Whereas pure chemistry leads to neglect of the needs of society and arouses little interest in the majority of students, the integration of pure and applied chemistry with other disciplines such as the human sciences could make it possible to study the connexions between the various sectors of science and society in a very practical way.*

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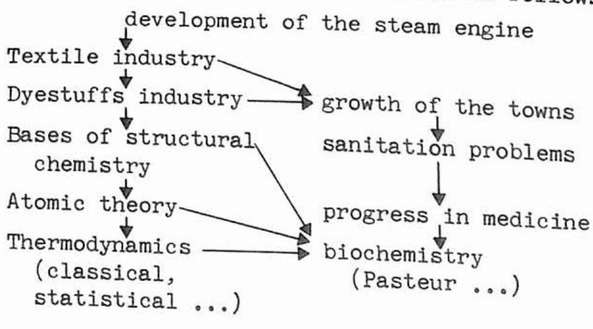
* A very thought-provoking suggestion for possible action to this end, illustrated by reference to the history of science is proposed by M. Minssen (personal communication) in connexion with Carnet's principle and its relationship with the development of society, which can be roughly represented as follows:


development of the steam engine
Textile industry
Dyestuffs industry
Bases of structural chemistry
Atomic theory
Thermodynamics (classical, statistical ...)
growth of the towns
sanitation problems
progress in medicine
biochemistry (Pasteur ...)

There are other ways of reflecting the needs of society effectively in education: by laying emphasis on sectors in which the practical applications are soon apparent, and by giving all students, not only those in applied schools, basic instruction in the theory and practice of technology, involving them in active participation in production. (20)

Integrated education, which tries to give a genuine training, should not be based on the traditional system of *ex cathedra* teaching, but should encourage and make full use of the individual work and research of the student: the aim should be to develop attitudes and to help the student establish his own working methods and learn to learn, development of these aptitudes becoming ever more necessary as knowledge acquired soon becomes outdated in our rapidly changing world.

The interaction between the requirements of society and educational systems can also be seen in the practical problems of selection of students and subsequent job opportunities. In simplified terms, one might say that in the socialist countries the individual is trained to go wherever society needs his work, universities and higher educational establishments selecting candidates in accordance with plans adopted by the state and with the results obtained by the candidates themselves. The problem of finding employment is therefore practically non-existent for graduates in these countries (where the question of an individual vocation is seen as an artificial problem). In countries where the free enterprise system operates, the *laissez-faire* approach seems to prevail in vocational guidance: the student chooses his course of study according to the career he wishes to take up, this decision seldom being based on the needs of society. He may even choose a sector in which there are no openings at all, and in such cases *de facto* limitation once more becomes operative (to which can be added the *de facto* selection based on socio-economic factors which is only very slowly tending to diminish). This raises the problem of graduate unemployment and of graduates having to readapt to employment in sectors which do not correspond to their initial specialized training. This problem could equally well be expressed in terms of the educational system's lack of adaptation to the needs of the society concerned; but one should also beware of the dangers which would arise if the university were obliged to reflect only the immediate needs of certain industrial or military sectors...

As far as the general public is concerned, it is very important that attention should be paid to the need of responsible citizens for information and that that need should be met.

There is, in the general public's negative reactions towards science, a very strong emotional element, fed by a general misconception about science and by nostalgia for a mythical past. The reaction against science should not be allowed to lead to a slowing down of scientific progress such that the complex situations created by scientific development can no longer be controlled for lack of the necessary tools. It is particularly regrettable that, most of the time, the general public has access only to the often over-dramatized information circulated by the popular press; scientists should make it their business to co-operate in circulating more balanced information. Thus, for example, it is generally believed that technological development exploits our human environment and impairs its quality, and that certain types of pollution are caused specifically by chemical industries. It would be important to demonstrate that chemistry is also in the forefront of research to improve our living conditions (new methods of limiting pollution, birth control, etc.) and is indeed already helping to protect the environment (for example the production of synthetic fibres based on petroleum may be regarded as an alternative to the exploitation of natural fibres to the detriment of natural ecological resources. (21)

As was pointed out at a symposium organized by the Council of Europe at Strasbourg (19 - 21 April 1971) on presenting science to the public, 'scientific popularization should not aim to transmit simplified, indeed debased, scientific information, but to give the national community the wherewithal to play a responsible part in the process of scientific development.' Seen in this light, the popularization of science has its own social and political part to play. (22)

It is to be regretted that scientists have not yet realized the use which they could make of the new media, and of radio and television in particular, to reach a wider public than that reached by the press (some excellent, but very limited, TV series do exist, such as that of Sir Lawrence Bragg in the United Kingdom).

Among scientists. The readiness of science to be concerned with social problems and a new social profession of science imply both mechanisms for technology assessment and a dialogue with users to ensure that the further progress of science is the reverse of a unilaterally imposed technocratic solution. (23) At the same time, a multidisciplinary approach should be developed to the complex structures constituted by those systems in which human activity is involved (in interaction with various elements of natural systems, collaboration by research workers trained in different methodologies might make it possible to extend our knowledge of domains which until now have been neglected although this would require some modification of the training of research workers. (24)

The integration of the needs and requirements of society into parameters for guiding the selection of subjects for research would place restrictions on scientists' traditional freedom in this sphere. This is a difficult and serious problem on which the Brooks Commission (1) adopts a rather ambiguous position: noting that in the past scientists guided exclusively by their own curiosity have rendered valuable services to society, it emphasized the need to establish new links both within science itself (between subjects which were until now isolated from each other) and between science and social objectives, though without detriment to the dynamism of science: for whatever the applicability of science, it needs to be independent in order to work out abstract conceptual patterns which in the initial stages are an end in themselves (making it possible later to apply them in very widely differing contexts). The aim is not to impede the work of science, and the consideration of social requirements does not imply a reduction in fundamental research: this is one of the basic problems with which science policy will have to deal. (1)

The social responsibility of science

Although science and technology work hand in hand, it is nevertheless important to make a distinction between science, the discoverer of knowledge, and technology, which translates this knowledge into know-how.

This is the first time that society has been asked to give an opinion on a problem such as that of the quality of life, while vehement voices are being raised to reject the dictatorship of experts who make decisions on their own and lead society towards an ever-increasing collective irresponsibility.

Although science can only develop in the name of pure knowledge, it will not survive unless it is fully and wisely used to improve human condition and not as an instrument wielded by one group to dominate another. (25)

As regards the difficult problem of priorities, ordinary citizens do not make the same choices as governments and industrialists (for example they give preference to medical research and research into pollution. (26) Hence the need to work out 'social indicators' to identify and quantify needs which are not reflected by the market: the emergence in our societies of an interest in the qualitative aspects of growth, together with a more comprehensive definition of social well-being, will call for much closer integration of science policy with overall economic and social policy. (27) Hence the further need to assess the possible technological options so as to try and organize technical progress. (This is a difficult problem: the standards applied may vary considerably from one technological context to another. Every nation pays an enormous price each year in road accidents, but is very alarmed by the low level of radiation emitted by nuclear power stations). (1)

For many scientists and economists, innovation alone can combat the consequences of its own excesses (28), provided that it can be carried out within guiding and regulating structures which will maintain a balance in technical progress. We already know of processes which should make it possible to avoid using up the resources of our environment, such as the use of solar energy (which is clean but not yet efficient enough), or geothermal energy, the possible use of which is now being investigated. There are remedies for pollution, such as closed-circuit recycling, or processes which would make it possible to reduce pollution levels immediately. Strict anti-pollution legislation could impose upon certain chemical industries rigorous standards which could be applied now, but which are so expensive that it is research into new reclamation processes which is being stimulated. (For example, it has been calculated that the power stations now in operation at Le Havre produce each year exactly the same amount of sulphur dioxide as that used by the two most modern sulphuric acid production plants in the same town, but there is as yet no method of reclamation which is economic enough to be practicable). It is easier to design and install anti-pollution devices in industry than in households which are numerous and dispersed, yet the latter contribute more to atmospheric pollution in towns than the chemical industry. The same is also true of water pollution, due to increasing use of household detergents. Research into the possibility of biodegradable detergents, and of photodegradable materials for plastic containers, is the only means of remedying the effects of certain aspects of technical progress which, in addition to their advantages, entail fearful consequences for our environment owing to the enormous number of users involved. (29) Marx showed years ago that chemistry makes it possible to change non-value into value (quoted by V. Labeyrie). (7)

CONCLUSION

Science and technology are an integral part of economic and social development, which implies a much closer relationship than in the past between policies for science and technology and all areas of socio-economic concern and government responsibility; 'a major challenge to science policy in the next decade may prove to be to find new goals for technological innovation, that related to the adaptation of work styles to the psychological needs of individuals rather than, as in the past, the adaptation of man to work styles set by technology'.

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The evolving demands of industry and other professions

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INTRODUCTION

Over the last decade or more, major changes have occurred in industry - and especially in the large-scale chemical industry - as a result of the systematic application of earlier research in physical or engineering science and of industrial economics. At the same time, the growing demand for university education has provided the impetus for advances in educational technology and for reshaping university courses. The opportunity now exists for examining how far university courses, apart from providing an education, are useful to chemistry students wishing to enter industry or other professions, and how this usefulness might be enhanced.

UNIVERSITY PLACES AND CHEMISTRY OPENINGS IN INDUSTRY

The demands made on university chemistry departments are to provide their students both with chemical skills and with a general education. Ideally, both these aims should be totally achieved by the combined efforts of staff and students. In practice, perfection in either aspect cannot readily be envisaged. Moreover, there should be an appropriate balance between the two. The point of balance varies with the emphasis placed by society on a number of factors, of which some may be enumerated: the tradition or even objectives of the university (a 'technological' usually differing from a 'classical' university); the choice by the student (who may perhaps opt for a course in 'advanced wave-mechanics' rather than for a course in 'petrochemical processing'), and, perhaps surprisingly, the ease with which chemical jobs in industry can be obtained by graduates in chemistry.(1) The ratio

$$\frac{\text{number of graduates produced annually}}{\text{number of chemical posts open annually}}$$

has become significant. If this ratio is less than one (that is, if there are more chemical openings than chemists), society's and industry's need is for chemists primarily; most students accept chemistry courses with a high content of vocational training because they expect to find jobs readily as chemists. If the ratio is greater than one (that is, if there are fewer chemical openings available than the number of chemists produced), then both society's and students' attitudes change because not all chemists can be employed as chemists - therefore they have to be employed in some other capacity. There is a greater demand for 'chemistry as an education'.

In any one country, the ratio changes over a period, as the number of university chemistry places provided and the number of openings in industry changes. These changes occur independently, and may thus cause hardship, in the Western industrialized countries and in the developing countries; in centrally planned countries, difficulties may be avoided by correct planning. In recent years, the trend in industrialized countries has been for university places to be made available at a faster rate, and for the growth in chemical openings in chemical industry to slow or even reverse because parts of the industry are approaching maturity.(2) There is then a discontinuity when the ratio greatly exceeds one; and a return to a ratio of less than one can only be achieved if students fail to enrol for the places provided. Although there are empty science places in the United States and the United Kingdom, such a drastic swing from science is not likely.

The ratio not only changes with time in any one country; at any one time, different countries or regions have very different ratios of output of chemical graduates to openings in chemistry. For example, Australia and Israel have for over a decade been producing many more chemistry graduates than the number of chemical openings might seem to warrant.

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However, in the German Federal Republic a surplus of chemists over chemical posts available is not expected (3) until chemists emerge from the newly established universities in the mid-1970's.

At any one time, what is written in one country about the needs of industry and whether or not they are served by universities, depends on the relation between the number of opportunities open and the number of chemist graduates. Therefore, there is a need for statistics on both chemists graduating and industrial openings in chemistry. Cases where both sets of statistics are available are scarce (4) and need to be supplemented. On the whole, one tends more frequently to find statistics on the numbers of graduates. Thus, the United Kingdom has for some years been producing more chemistry graduates annually per million of the population than any other country (2) and for that reason produces statistics both of entrants to university departments and of degrees awarded and first employment of graduates.(5) Statistics are also provided annually by the news organs of chemical societies in the German Federal Republic (6) and the United States.(7)

By contrast, there appear to be no official statistics of job opportunities in chemistry, though the subject is receiving increasing attention. It is estimated (8) that in the United Kingdom 600-750 job openings exist annually for chemists in the chemical and allied industries, whereas there are nearly 3000 university places for chemists annually (about 2500 graduates being produced annually). The United Kingdom of all industrialized countries thus suffers most acutely from the problem of students with great expectations of using the chemical knowledge they have acquired (9) but with insufficient openings to permit fulfilment of the expectations. The problem also faces the less developed countries where fewer chemists graduate but where there are hardly any industrial posts for chemists.

CHANGES IN THE CHEMICAL INDUSTRY

While the growing affluence of the industrialized - and indeed of the emerging - nations has led to a demand for more tertiary education and an increase in the number of university places, the chemical industry has also been changing. In the 1950s and 1960s, the switch from coal to hydrocarbons (petroleum fractions or natural gas) led to a complete change in chemical technology. To invent, develop and implement this change required numerous chemists and chemical engineers. In the mid to late 1960s this switch was complete. The petrochemicals industry at that time had been growing at about 15 per cent per annum (compared with about 9 per cent for the chemical industry as a whole) for about 20 years. It was by then very large, capital-intensive, and production-oriented. Not only have petrochemical processes replaced traditional coal-based or fermentation processes, the products - cheaper than before - have penetrated into new markets. Tonnage polymers (polyethylene, polystyrene, etc.) have in part replaced traditional materials (wood, metals) in use, and synthetic fibres have completely replaced silk and made important inroads into wool and cotton markets. The use of films for packaging and other purposes has greatly expanded. This exponential growth, partly at the expense of traditionally used materials, cannot of course go on indefinitely. All exponential growth must slow down sooner or later.

At the same time, chemical plants had grown to such a large scale that the investment in new plant could only be faced with well-tried processes. As a result, within a relatively short period, the petrochemical industry has passed through a true discontinuity.(10) It now requires fewer chemists both in research and in technical processes. The petrochemical industry is still a large employer of chemists, but - in spite of its greatly increased size - it is recruiting only a small fraction now of the number of chemists it wanted to recruit 10 years ago. Moreover, of the chemists in that industry only a relatively small proportion stay in chemistry - the rest move into production, techno-commercial or commercial departments or increasingly use managerial rather than chemical skills. If the entry of chemists into research departments is blocked because the resources devoted to research are diminishing, then the main reason for using chemists in industry disappears. For tasks other than chemical research, people from other disciplines are equally suitable: a physicist, mathematician, indeed a specialist in ancient history (if he is able and numerate) will be able to run a plant, analyse a system, or assess cost-effectiveness.

So much then, for the fundamental change in the large-scale petrochemical industry which embraces part of the polymer and fibres industries. There is a second component in the modern chemical industry, namely that dealing with fine chemicals having specially desirable effects. Outstanding among these are biological effects - restoration or maintenance of health, and prevention of disease in humans or animals; and increase in food production through pest control. These industries are large, but they are still growing fast and in this and in other ways they differ from the petrochemical industry. They are not capital-intensive (but research-intensive) and highly market-oriented.

And, more important in this discussion, they require highly experienced chemists whose career pattern differs from that of chemists in the large-scale capital-intensive chemical processing industry. Many more chemists in the 'effects chemicals' industry remain chemists - in research, development or technical service; fewer become managers. Their main preoccupation is in fact the need to keep up to date in branches of science and technology related to their own expertise.

When we discuss 'the evolving needs of industry', therefore, we have to understand clearly that there is not one chemical industry with a homogeneous set of needs. There are two strongly differing industries, the mature largescale industry (inorganic and petrochemical) and the fine chemical/biochemical industry. Their needs often conflict, and each of them has a wide range of resources and of needs. Each part of industry is changing and the rate, indeed the direction (insofar as the large-scale industry is reducing manpower while the biochemical industry is increasing research numbers) of change differs.

NEEDS OF INDUSTRY

Because of the differences in their background, members of the chemical industries cannot usually speak with one voice when discussing university courses and graduates. Vague criticism seems to emerge (11), especially from working groups and symposia. Recognizing the diversity of industrial interests, few industrialists have the temerity to speak out clearly (12, 13, 14, 15, 16) and offer constructive suggestions.(17) The distinction between the permanent chemist and the manager who happens to be a chemistry graduate has been very clearly drawn.(18) Not surprisingly, academics, much more experienced in addressing the public, have been more vocal, even though few have had as much experience in industry (say 4-6 years) as most senior industrialists have had in universities. The real difficulty, it seems, is to say something that is constructive and acceptable to the parties involved.

The need of industry that does not change is for able people with flexible minds (19); all industrialists seem agreed on that. Granted the ability of good graduates, the problem resolves itself into fostering flexibility and avoiding over-specialization. Solutions proposed include the encouragement of conscious awareness of the need for adaptability (17), curricula providing interfaces with and excursions into related sciences or other disciplines (17), and interdisciplinary work resembling that increasingly practised in industry.(19) More contact with practical problems (17) has also been proposed. Further proposals (13) include emphasis on scientific method during attack on a short research problem, acquaintance with operational research methods, with communication processes and behavioural science applications, and recognition of change and its consequences. All these proposals, if implemented, would make the transition from university to industry easier for the graduate, and let him participate in his new environment with more confidence, irrespective of the major discipline studied at his university. Chemistry offers the student the advantage (9) that it deals both with concepts and with numbers and can thus be widely applied: a corollary is that the student would be unwise to throw this advantage away by taking too narrow a view of the science or of his future. Certainly his usefulness in industry will be impaired thereby.

CHEMISTRY AS AN AID IN OTHER PROFESSIONS

Chemistry may be regarded as an 'enabling science'.(11) Not only is it widely useful itself, but it requires both numeracy and concept-formation: the resultant combination forms a sound basis for other disciplines. One might therefore expect students of other disciplines to wish to master the principles of chemistry. Indeed, for some professions - medicine, pharmacy, and chemical engineering, for example - chemistry is essential. It is therefore included in the normal syllabus. Chemical engineering education, in particular, has come under critical review (20) and emphasis on the properties, durability and compatibility of materials has been suggested (21) as important in a chemistry course for engineers.

Students of other disciplines, agriculture (22) and biology (23), for example, also find chemistry valuable, yet few biologists read chemistry. Much of the normal chemistry course appears irrelevant to the intending biologist, and much that might be relevant is omitted.

The wider usefulness of chemistry is recognized in studies of the earth sciences; but not in, for example, legal or business studies. Yet there are points of similarity: clarity of definitions, requirements of numeracy and recognition of similarities form important components in a study of chemistry.

Careers based on, or using, chemistry may be summarized in terms of activity, for example:

Career	Chemistry-based	Using chemistry as part of education
Laboratory	Process or product research; analysis and quality control	
Administration	Technical administration; patents and licensing; library and information service	General administration and commercial office work
Artistic/ Creative	Preservation and authentification of objects (in musea etc.) Packaging Technical journalism	Journalism
Industrial	(Which industry) Production; Technical service; Technical sales	Commercial activities Transport
'Service'	Teaching (lecturing); forensic science	Civil Service

THE ROLE OF THE UNIVERSITY

Just as the last decade has seen major changes in industry, so important changes have occurred in universities. Numbers, attitudes, courses, all are changing. As regards chemistry education, several trends can be clearly distinguished. Most important is a wider recognition of the fact (24) that the old division of the subject into organic, inorganic, physical and practical/analytical is harmful: it prevents the student from grasping the essential unity of the subject. Such understanding early on is especially important if chemistry is to be put to use both academically as part of the education of a student primarily concerned with some other subject, and industrially. Moreover, the old divisions inevitably lead to overlapping or gaps, and extend the course, so that some of the student's time could be better spent.

If a university course in chemistry is to be a means to an end, what is needed is a 'basic' treatment of the principles of chemistry. This is what students want if they are primarily interested in other subjects or professions, or in careers other than extended academic chemistry. In addition to this treatment there might be optional courses in the chemistry department to help to build a bridge between chemistry and the ultimate vocation: aspects of biological chemistry perhaps for agriculture, medicine, pharmacy; forensic chemistry for lawyers; and suitable case studies in chemical technology (technological economics) for chemists seeking industrial careers.

These wishes are best put into practice in one of two ways: first, in a fully modular course offering optional chemical units as well as other options and, secondly, in a 'core-plus-options' course where the choice of chemistry is more restricted but 'bridge-building' is possible through a variety of courses, both within the chemistry department and in other departments.

The choice for students preparing for some other profession is relatively clear: they will take the course permitting the best understanding of the principles of chemistry in the shortest possible time; and they may add a course that is relevant to their chosen profession. But what should the university chemistry department do for students interested in (but not as yet wholly committed to) an industrial career? Industrial comment is not really very helpful here. It is difficult to translate the need for 'education', which means different things to different people, and 'adaptability' into a university syllabus or course. Yet some universities have been sensitive (25) to students' needs and industry's advice, particularly to the feeling that students should know more about society and its problems. In the centrally planned countries, in particular, a course in socio-political thought is given to all students; this may not always be very broadly based, but few Western departments of chemistry seem to provide such courses for scientists at all.

It is widely agreed, too, that actual work in industry helps students inclined towards an industrial career. Because of the differences in objectives between the two types of institutions, indeed the two ways of life, the effort needed to acclimatise students to industry is substantial. In Cuba 50 per cent of students' time is spent in industry at tasks increasing in professional content as the student progresses in the university course. In the United Kingdom's technological universities and polytechnics, 25 per cent of the time is devoted either to one 1-year spell or to two 6-month spells in industry; and in the German Democratic Republic, chemists take industrial vacation jobs. Such extra-mural industrial work is valuable for the student, particularly before his final specialization.

Not only does the student see industry at work, the real differences between the academic and industrial environment become obvious to him. The importance of project work, of recognizing and dealing with behavioural and communications problems, and of interdisciplinary team work may be experienced at first hand. Equivalent preparation for life outside the university is difficult to provide from within. Some universities have special lecturers ('Honorarprofessoren') from industry who provide suitable material for discussion. Industrial work may be simulated.(26) Many students now do project work - often a simple research problem that develops ability for making analytical deductions (even though constructive problem solving may not be involved). The problems, however, are usually entirely chemical and do not take account of economics or legal matters; and they are usually too short to provide experience of, or an insight into, operations research techniques. For this, integration of the problem into an industrial project is necessary: but such collaboration is still exceptional, even though the need for it is increasingly recognized. Such collaboration puts into perspective the role of the chemist in industry: students quickly learn that only a part of the chemist's contribution is chemical; and that a flexible approach to interdisciplinary ideas and problems is important. This encourages them to seek some of the other skills they will need.

These include (27) computational skills, operations research, behavioural science (psychology), economics, and certain legal branches. These skills are all directly applicable in the industrial situation. Indeed it has been suggested (in Czechoslovakia) that an industrial chemist who has not acquired them in his academic studies should not have a university degree but a diploma; this attempted differentiation between education and training is significant.

The problems encountered in transferring knowledge and experience across the university-industry interface (in both directions) are common to the industrialized countries. The problems of the developing countries are different in kind. The scarcity of major manufacturing industries and particularly of industrial research and development makes the placing of students and collaboration on projects extremely difficult. Students' interest tends to concentrate on the local primary resource industries (agriculture, mineral extraction and processing, and the simple local manufactures, e.g. cement).

Thus a vicious circle is perpetuated whereby these countries fail to acquire modern manufacturing technology. International exchanges of students and staff might go a little way towards meeting the needs of the local population for sophistication in technology; but such exchanges have hardly begun and funds are scarce.

The full solution of the problem is outside the scope of the university chemistry department, which can, however, make some contribution by initiating co-operative exchange schemes, for example with industrial research associations, overseas research and development departments of multinational corporations with local connexions, and international agencies.

One vital function of the chemistry department within the university is to make it possible for the student to acquire the fuller academic 'education' which he feels he needs for life outside the university. The course should contain options not only in natural science subjects - often physics and mathematics are compulsory in the first two years, anyway - but in social science and economics. There is a general feeling that 15-20 per cent of syllabus time should be spent on non-scientific subjects. Just as there is a need for 'relevance' in the chemistry presented to, say, biologists (23), so these outside courses must have 'relevance' and meet the students' need. This inter-departmental co-operation may be difficult to arrange, but it is essential; otherwise the chemistry department itself turns into a microcosm of a university, providing specialist lectures on a potentially wide range of subjects. These may include, as already mentioned, socio-political thought, including the function of science in society (28), social science and economics and, in addition, relevant parts of computer science, operations research/statistics and behavioural science (especially communications theory and psychology). Such inter-departmental and inter-faculty activities are rarely organized in the absence of real competition among universities: competition occurs in the U.S.A. for financial reasons, but in other countries only when the number of students wishing to enter university declines. This is the position now in the United Kingdom and to a smaller extent in Canada.

More complex subjects like 'research policy' (University of Konstanz, German Federal Republic) or 'business studies' might be very attractive to students, but are perhaps better treated at the post-graduate level. Lecturers in these subjects gain in credibility if they have substantial practical experience of the subject: an entirely academic treatment may deter students wishing to use these courses as a preparation for careers in industry.

With such a wide range of choice in university subjects, and perhaps also in industrial experience, communication among students becomes increasingly important. Seminars where participants engaged in different activities exchange experiences help greatly to clarify the participants' thoughts, to monitor achievement against objectives, and to spread educative knowledge. University staff may, but need not, be present, although they might gain a valuable insight into their own efficiency in communicating with their students. Too little activity along these lines is noticeable today.

With a wide choice of optional courses, the student can prepare himself for the task he sees himself performing in the future and thus get away from the conveyor belt system of a decade ago when, at the end of their course work, all students had heard exactly the same material.

The student benefits by having prepared himself - psychologically and educationally - for the time when he leaves the university; and the future employer benefits by having candidates for entry who have some knowledge of the problems to be tackled. The chemical education received by the graduate is one important part of this knowledge: but except for the 'permanent chemist', who is 'topped up' at intervals, it is insufficient today. Such a new graduate would require extensive supplementary training (29) which an employer can ill afford and is ill-equipped to give.

SUMMARY

The university chemistry department has students with a wide range of interests in chemistry, in careers based upon chemistry, and in professions wherein chemistry plays merely a background role. The diverse needs of these students may be met by provision either of a wholly modular course (offering a wide range of chemical and other course units) or of a chemistry-core-plus-options course, where the options contain chemical and non-chemical topics/subjects. About 15-20 per cent of the course should be in non-scientific subjects.

The chemistry department should concern itself with transferring knowledge and experience across disciplines and across the university-industry interface. It should foster educative student placement in industry during the university course, and hold informal seminars in which students can exchange views on their experience in different activities.

Options likely to be of most help to students who wish to prepare for a career outside the university include socio-political thought (including the function of science and industry in society), social science, economics, computer science and related subjects (e.g. operations research and statistics), behavioural science and related subjects (communication, psychology).

More complex subjects like business studies or research policy can follow as postgraduate courses.

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The evolution in the nature and structure of chemistry

by B. Jeżowska-Trzebiatowska

INTRODUCTION

Apart from physics, chemistry is the science most involved in understanding the essential nature of matter. Chemistry deals with complex systems i.e. atoms, molecules and their arrangement. Each set of molecules, one molecule or an atom form the uniform, unique quantum-mechanical system.

Chemistry is a very broad science, ranging from physics to biology. The boundary-lines approximate so closely, that it is difficult to find clear divisions.

In the last 25 years, the development of chemistry has been exponential. This was caused mainly by the development of theory (thermodynamics, quantum chemistry) and by the appearance of new fields of studies (defined very often as chemical physics). Diffraction methods, spectroscopy, nuclear and electron resonance, magnetic and dielectric methods etc., allowed penetration into the electronic and molecular structure, the determination of the atomic distribution in compound systems and the recognition of interatomic and intermolecular forces.

On the other hand, the development of techniques and methods of synthesis (high vacuum, high pressure, high and low temperatures) allowed the multiplication of the number of the systems already known. The possibility arose of learning about the inner structure of molecules and condensed phases, and its correlation with properties.

These advances enabled us to obtain compounds and materials of desired, programmed properties. Progress in studies on dynamics, enabled the tailoring of chemical processes, producing rapid development in industry, which in turn stimulated further researches.

Achievements in studies on structure and mechanisms in complex systems allowed chemistry to enter biology, resulting in delineation of new fields, such as molecular biology. Hence, the application of large systems analysis became indispensable in chemistry.

Development of all these new fields has brought forward new needs which chemistry must satisfy, and caused the step-by-step destruction of the traditional structure of chemistry (inorganic, organic, physical) based on 19th century discoveries.

The necessity for the common application of physical methods in studies led to the integration of physical chemistry with other parts of chemistry. On the other hand, particular fields of physical chemistry, e.g. thermodynamics, kinetics, catalysis, electrochemistry, physics and chemistry of solids have become independent branches of the chemical sciences, presenting individual, specific features.

Rapid developments of the chemical sciences have also blurred the boundary between organic and inorganic chemistry, while some branches have become separate sciences, with their own set of methods, and a specific approach to the problems to be solved: for example, complex chemistry, macromolecular systems, biochemistry, nuclear chemistry.

THE NEW STRUCTURE OF CHEMICAL RESEARCH

Research in chemistry is the best reflection of the new, changed character of the field. The chemist penetrates ever deeper into the structure of matter through the development of accurate research methods and the enormous progress in theory. The chemist now enters fields which traditionally belonged to physics, such as the structure of solids and liquids. This is the consequence of the examination of the chemical compound not only in its molecular, but also in the environmental state, as it really is in systems of strong interatomic, interionic or intermolecular interactions. The fascinating and challenging problems of living substances require high skill for work on their systems. Chemistry opened the way leading to learning about the functions of living organisms and plays a leading role in this domain. The electronic materials of today: magnetic materials, semiconductors, superconductors, lasers, are chemical compounds in the solid phase, or liquids. Only the complete overlapping of chemistry and physics has led to present developments in science and technology but further integration will be necessary in order to achieve the future revolutionary progress of science. We are witnessing the obliteration of boundaries between all the domains of chemistry, and the creation of new specializations - organometallic chemistry, coordination chemistry, biophysical chemistry, bioorganic and bioinorganic chemistry. All these indicate the decay of boundaries among the traditional divisions of chemistry. Macromolecular chemistry, because of its importance in biological systems and polymers - the new materials of today - is of growing importance. The boundaries between basic and applied studies are disappearing. The needs of technology are now so great that studies require good preparation both in theory and in experimental work to become effective and forward looking. Basic studies nowadays are very rarely ad hoc, but are planned, and lead to better understanding, which may provide new openings for technology. Structure - dynamics - synthesis, are the three basic fields of chemical research, and remain in close relation and dependence on each other.

The greatest progress was achieved in studies on the molecular structure of chemical compounds and in their examination in the condensed phase. Through new research methods one may obtain reliable data about the structure and conformation of molecules, about interatomic distances, electronic structure, the character of chemical bonding and their dependence on the structure. Intermolecular interactions have been recognized and are the subject of many-sided examination. Furthermore, we have gained a suitable mathematical language for the description of the structure and energetics of a molecule. The new methods allow us to determine structure even in short-lived intermediate states.

Studies on the condensed phase structure are becoming ever more precise, especially in the case of solids. The difficulties in studies on structure and properties of the collective systems have been eliminated thanks to new physical theories and experimental methods, which allow us to obtain data even under extreme conditions (high and low temperatures, high and low pressures).

The role of computers in chemical studies should be emphasized. The chemist makes better use of them than other scientists, since he is dealing with more complicated systems, and only with the help of computers can he solve the problems and get his questions concerning the substance answered.

The traditional division of chemistry loses its reason in scientific research. Understanding the subtle structure of matter has created a new field of science - molecular engineering, and next, material science.

In chemical dynamics, great discoveries may be expected, because less has been achieved hitherto in the progress of understanding and theoretical knowledge of mechanisms, of chemical transformations, than in the field of research on structures. The possibilities are great. Thermodynamics now has its theoretical basis - theoretical thermodynamics and statistical thermodynamics. In kinetics it is now possible to study fast and very slow processes in close relation. We witness the emergence of electrochemistry on a sound theoretical basis, and hence progress in that area may be expected. Chemical engineering, based upon the analysis of large systems, enters a new stage of development.

The purpose of this short introduction is to illustrate the new character of chemistry, which turns out to be the real molecular science.

Chemistry extends over new areas of science and new areas of human activity. It is a more vivid and creative science than any other. Progress in other branches of science and technology is determined by progress in chemistry. The new division of chemistry was applied to material prepared for the 2nd Congress of Polish Science, in order to classify and to estimate the state of chemical researches, their results and future development.

This allowed us to obtain a clear picture of chemistry and proved to be better than the traditional division.

THE NEW STRUCTURE OF CHEMISTRY TEACHING

What developments can we see inteaching, in the light of the rapid developments of chemistry?

It should be emphasized that in spite of all the progress in science, its teaching does not keep pace. The rapid development of chemistry gives rise to growing difficulties in teaching. Trials and experiments are carried out all over the world. The problem is discussed in various contexts. Two events which indicate the validity and importance of the problem should be mentioned here: the Conference at Frascati (Italy) organized by IUPAC (1) and the Conference in Colorado (U.S.A.) organized by Unesco and IUPAC.(2)

These conferences had woken up the majority of universities and university-level institutions from their slumbers. Discussions, exchanges of experience and simultaneous challenges are the best guaranties of progress. The experiments, carried out in various countries, some very successful, are involved with the integrated picture of all domains of chemistry, and of chemistry and physics.

THE INFLUENCE OF CHANGE ON THE CHARACTER AND STRUCTURE OF CHEMISTRY EDUCATION AT UNIVERSITY LEVEL

First of all, it should be emphasized that the future of chemistry and the future of industry and many branches of technology, and even the future of mankind depends on the education of first class personnel, aware of the developments of chemistry. This is a simple statement of fact. Education must be coupled directly with scientific investigations, because research depends on education, and education depends on the level of scientific research carried out in a given university by the staff involved in teaching.(3)

There are two main directions in the education of a chemist: basic chemistry and applied chemistry and chemical engineering. In Anglo-Saxon countries (United Kingdom, U.S.A., Canada, Australia) both are represented at universities (chemistry, chemical engineering). In the majority of European countries, the education of engineers is carried out in special institutes, devoted only to chemical engineering, or at the chemistry faculties at technical universities, or both systems are present simultaneously.

No matter which of these two directions teaching follows, it is indispensable to educate the modern chemist, accustomed to scientific research, to look for new ways in science, in technology and in teaching. He must be trained to think independently, to be provided with up-to-date knowledge, and to know how to improve on it.

In contemporary education the basic role is played by theory - theoretical chemistry, theoretical mechanics (as quantum chemistry), theoretical thermodynamics (statistics), all these reflect the changed picture of chemistry.

This situation is not yet realized in all countries, because of the lack of adequate staff and because of an attachment to traditional teaching.(3)

The next requirement for modern education is to provide students with a knowledge of, and ability to apply, modern research methods, and the simultaneous ability to analyse the results of studies using computers. Theoretical and physical research methods founded on basic chemical knowledge give students the possibility of undertaking serious research on structures. The teaching of chemical synthesis is also very important, but should be carried out in such a way as to give the student the possibility of creating new substances. In the course of studies it is necessary to learn chemical dynamics, based upon theory (thermodynamics, kinetics) and integrated with experiments. Chemical dynamics is the basis of knowledge about the mechanisms of chemical processes.

Such a programme of chemistry teaching must be based on the new structure of chemistry.(4) Attempts and experiments have been undertaken on the structure of both education and programmes.(4-9) G. Hammond and R. Nyholm are precursors of the new programme based on the new divisions of chemistry.(4)

In 1966, G. Hammond and H. Gray initiated a new first-year course which was termed the 'Hammond curriculum'. The programme and the first results of this method were reported by G. Hammond in Frascati (1968).

At present there are only curricula based on some variation of the Hammond curriculum. The fundamental philosophy of such curricula is a resubdivision of chemistry, because the traditional boundaries are meaningless and perhaps harmful, and a better way of teaching chemistry is to recognize divisions into Energetics, Structure and Dynamics, rather than into Organic, Inorganic, Physical. The unifying concepts are very important in this programme. The years are divided into parts (10), for example: first year, first semester - microscopic (atomic structure, energy levels, spectroscopy, bond properties) and macroscopic (mole concept, thermodynamic functions, gas laws, equilibrium constants); first year, second semester - micro (molecular structure), macro (acid, base, redox thermodynamic functions) and dynamics. The first part of the second year consists of 'physical methods', the second and third are devoted to inorganic and organic chemistry. In these courses, the earlier inclusion of crystallography, spectra and molecular orbital theory allows the other materials in the course to be presented at a really sophisticated level. The third year is divided into two parts: thermodynamics via quantum statistical mechanics, and dynamics (with biochemical aspects).

The student's work in the laboratory is integrated and largely takes into consideration physical methods. In this Hammond curriculum, promising students are stimulated to chemistry, while poor students are dissuaded from chemistry earlier than in the usual approach.(10)

The Hammondoid curriculum conception, unifying traditional branches of chemistry, is very interesting and these programmes should be continued and improved.

The departure from traditional divisions will undoubtedly occur very soon. This would enable students to understand the essence of chemistry more fully and to develop a wider outlook on all problems related to matter.

This question was discussed during the International Conference on Education in Chemistry (1970, Colorado),(2) in the section dealing with the structure of chemistry (G. Hammond and Sir R. Nyholm, chairman).(4) An alternative concept of dividing chemistry into three parts was presented:

1. Structure and physical properties of pure substances;
2. Chemical transformations;
3. Application of chemistry to complex systems.

This suggestion facilitates the classification of certain very important sections within one of the three proposed fields. For instance, section 1 would comprise spectroscopy, diffraction methods, magnetochemistry and other structural methods; section 2 would comprise kinetics, thermodynamics and techniques of synthesis; section 3 would include biochemistry, geochemistry, molecular engineering and material science. This alternative division seems to be more favourable and provides better solutions for complex systems.

No doubt many countries have succeeded in achieving considerable progress in integrated education reflecting the altered quality of chemistry but the present writer is most familiar with the efforts made in Poland.

These efforts consist of:

- the large-scale introduction of mathematics into the chemical studies (4 semesters obligatory and 1 semester optional);
- the introduction of an advanced course of theoretical chemistry (quantum chemistry, theoretical mechanics);
- the introduction of an X-Ray crystallography course;
- the introduction of a course in nuclear chemistry (1 semester);
- the introduction of short courses (Wroclaw University and some others) in electronic and vibrational spectroscopy, magnetochemistry, radiospectroscopy and other physical methods, thus providing strong foundations for research work by students (generally chemical physics);
- the introduction of an integrated laboratory of structural chemistry (1 semester, introduced at Wroclaw University in 1964). In this laboratory, students are taught to solve a definite structural problem on a presynthesized substance by single-handed selection of research methods with utilization of experience gained previously;
- the extensive application of seminars simultaneously with lectures starting from the first year of studies.

These new features and a modified structure of chemistry have been most successfully included in postgraduate studies both in lectures and seminars closely related to the research work being carried out.

In some American universities, specialist minicourses (8) in 3-week minisemesters are being introduced. These minicourses comprise certain branches of catalysis, gas chromatography, etc. They are suitable for laboratory work in modern fields. Some universities have introduced integrated laboratory courses (6, 8, 11), where only a general outline of the work is given and where the experiments are mainly prepared by the students. This makes it possible to encourage students' initiative. The integrated laboratory course introduces comprehensive material in the form of specially planned experiments instead of analytical, organic and physical chemistry. The laboratory courses introduced in the University of Pensylvania are being carried out as individual exercises on scientific problems.(12) Such courses have often a complex interdisciplinary nature. Owing to the rapid development of theoretical chemistry in recent years, it has become necessary to establish a reasonable equilibrium between theory and practice. It was generally accepted that the percentage of analytical chemistry should be diminished but that modern analytical research methods should be developed since these methods are commonly employed in industry and also seem to extend students' horizons.

As an example of a new trend in teaching chemistry, the experience of the German Democratic Republic may be mentioned. Two general aspects are realized in this programme: (a) all traditional subject headings - inorganic, analytical and physical chemistry - are replaced by other headings; (b) the theoretical - mainly physiochemical - part of teaching is shifted more to the beginning of study than is the case in the traditional programme.

Thus chemical thermodynamics and kinetics are given during the first and second year, simultaneously with laboratory experiments. Then follow the principles of chemical reactions and synthesis including the traditional areas of inorganic and organic chemistry. Analytical chemistry is covered under the heading of chemical equilibria, given just after the lectures on chemical thermodynamics. A large part of traditional inorganic chemistry is included in lectures on structure and valency. The basic study of chemistry is realized during the first two years. The third year introduces specialization in three different directions - in theoretical chemistry, chemical engineering and synthetic chemistry. Special lectures are given for each topic.

There are several disadvantages in the programme as presented: first of all, the knowledge of experimental chemistry is generally insufficient. The main problem consists of achieving a suitable combination of the theoretical and experimental parts of teaching, but this difficulty is common to all attempts at improving the teaching of chemistry.(18)

Huge stores of chemical knowledge and the simultaneous growth of contemporary chemistry require another type of work to be carried out with students - preferably in small groups with constant stimulation of individual work. Such a system was introduced long ago in some countries (U.S.S.R., Poland, Czechoslovakia and others) and the results are remarkable - provided, of course, that the system is properly carried out by suitable teachers. It is worth noting that a system of individual education (Poland, U.S.S.R.) is available for extremely gifted students with specialized interests. During the course of individual studies (last two years) the student remains under the guidance of a selected scientist, a specialist in the specific field. Extremely gifted students are given an opportunity to undertake research work during undergraduate studies, starting from the second year.

It is also worth noting the good results which have been achieved for many years in England through the tutorial system. In spite of the shorter duration of university training in comparison with other countries - because of properly specialized secondary schools and working with small groups (in colleges) - the results obtained are often better than those from studies of longer duration in other countries.

In my opinion, the most important factor has always been and will remain the teaching staff, their scientific standard, eagerness in scientific research work, understanding of developments in science and their enthusiasm for the teacher's and tutor's work. These considerations determine the results.

A lowering of the barriers between teachers and students, observed almost in all countries, has undoubtedly contributed to progress in tuition owing to improved transmission of knowledge.

Changes in the nature of chemistry make it necessary to look for new methods of knowledge transfer, because students are required to master a number of essential problems and data within a relatively short time.

Several experiments carried out in recent years in this field should be noted - programmed tuition, computerized teaching, the Keller system. All these methods relate to first-year university teaching.

Programmed teaching (8, 14, 15) employs published material which contains sequential information to be acquired by the student and test questions. In the so-called branched systems, some sections may be omitted and dealt with in case the tests give negative results. The programmed book system exhibits a number of negative qualities (it is schematic and gives only a fragmentary view) and only one positive quality: it excludes any possibility of gaps in the material acquired. Some United States universities use this type of teaching for basic studies on chemical bonding or for a concise course in organic chemistry and chemical nomenclature.(14) This system should be used as a supplementary one only and should not be employed for teaching wide and general branches of chemistry.

Computer assisted learning (8, 16) which has been developed in recent years, has an advantage over programmed (book type) teaching in making it possible to converse with the computer. A computer provides information and test questions and also answers questions as well as correcting students' answers. Thus it is not a kind of encyclopedia but rather a 'simplified teacher'.(16)

Use is made of digital computers, analogue computers and combined systems. Logical systems employed are the tutorial and the Socratic systems.

The first system, which is simpler, is based upon questions and answers. The second one offers discussion and conversation with the computer (ELIZA system developed and applied in MIT Education Research Center, Cambridge, Mass.).

One of the earliest and best known systems is the Plato system (Programmed Logic for Automatic Teaching Operation) employed since 1950 in the University of Illinois, U.S.A., and subsequently in a number of secondary high schools, colleges and state universities. The system is based on the extensive utilization of television and graphic materials and is therefore particularly suitable for learning stereochemistry, reaction mechanisms. It has also been employed for teaching NMR (nuclear magnetic resonance).

Mention should also be made of an alphanumerical-graphic system (University of Texas Course-Writer system) applied in laboratory work. It was applied in teaching qualitative and quantitative analysis and in spectroscopy. Extensive work is being carried out on the use of computers for dealing with atomic and molecular structure and chemical bonding (Santa Barbara University). At present about 200 colleges and universities in the U.S.A. employ this system to a certain extent and their number is rapidly growing. It is generally accepted that its application to selected fields of chemical science does not lead to rote learning and the results obtained are often favourable. Application of computers in tuition at a higher level appears to have been a comparative failure.

The Keller Plan (PSI),(17-20) developed mainly in order to convey the basic essentials of chemistry in a highly efficient and systematic way in order to avoid a perfunctory acquisition of the subject, has been introduced fairly extensively. It enables individual teaching at a higher level. It is beyond question better than conventional programmed learning or computerized systems since it permits the establishment of a direct contact with the teacher and, more important, the discussion of errors. The results obtained are encouraging and the stability of knowledge exceeds that acquired in conventional teaching, as shown in a number of universities in the U.S.A., Canada and Brazil. This project provides gifted students with the possibility of shortening the period necessary for the acquisition of a subject.

It would seem that the Keller Project contains some hazards because of incomplete transfer of the subject and a deficient development or broadening of the student's horizons. It would be advisable to combine the Keller Project with lectures to a large extent. A more generalized view of the rapidly growing science as well as of the integration of particular branches undoubtedly results in a good lecture. The lecturer's personality and its effect on students' personalities enable us to humanize the teaching process. The lecture should present problems, stimulate scientific curiosity, and arouse confidence in the great future of chemistry. It should not, however, constitute a system of questions and answers by providing encyclopedic facts.

THE NEW CHEMISTRY IN SECONDARY SCHOOL TEACHING

It should be impossible for students to encounter modern chemistry for the first time at the university. The teaching process in the secondary school should introduce young people to modern chemistry, leading to new discoveries.

The young should look at it as at a great science, leading to knowledge and the mastering of complex matter, as a science of enormous potential whose genuine future is still taking shape, as a science which brings not only knowledge but also prosperity to all mankind, as a basis of industry and the latest technology, as a science which improves human health and prolongs life, as a basis of biology, medical and pharmaceutical sciences.

The most important factor is a good teacher: therefore the training of good modern teachers, which is defective in most countries, is very important. Common efforts, based upon international agreements, should be undertaken. Chemistry is taught too conventionally in the secondary school, on the basis of old patterns and the traditional divisions of chemistry. (21, 22)

The most considerable progress has been made perhaps in the United Kingdom where studies carried out in both secondary schools and universities indicate the great importance of initial education.(23)

The secondary school should already reflect the integration of such sciences as chemistry, on physics, on biology. Exciting topics and development trends should be pointed out.

The secondary school can provide firm principles of chemistry integrated with physics, on a good mathematical basis. Teaching processes in the secondary school are different in various countries. It is most essential that the teaching of chemistry should take place in the last grade of the secondary school. This provides an excellent introduction to university studies and stimulates recognition of the importance of chemistry as a basic science and its significance in the economy. In most countries chemistry is taught, in fact, for a few years, including the last grade of the secondary school. A regrettable exception is Italy where chemistry is taught for only one year at school - in the penultimate grade. In some countries (for example, Poland) chemistry is not taught in the last grade of the secondary school, which militates against an interest in the exact sciences.

In many countries, specialist combinations are being introduced during 2-3 years; in England this system was adopted long ago. The most popular and helpful one in the United Kingdom is the specialist combination where particular emphasis is put on mathematics, physics and chemistry; the combination chemistry, physics and biology is less popular. In the Federal Republic of Germany, specialist combinations comprise physics and chemistry; in Poland, chemistry and biology. This last combination is less helpful for the future development of chemistry since in this case chemistry appears only as an auxiliary to biology.

Given the present tide of development and the significance of the exact sciences, the specialized combinations are the only way to achieve a suitable preparation of students for both the basic and the applied sciences. It is possible to arouse interest in chemistry and in research work in this field in the secondary school. It seems that the best specialization in the secondary school is a combination of mathematics, physics and chemistry or, alternatively, physics, chemistry and biology. The latter combination would comprise preparation for biological, medical and agricultural studies.

In order to master chemistry properly, teaching methods should be improved. The Nuffield system (24-27) introduced as an experiment in some schools in the United Kingdom, seems to yield good results. The Keller system may find some application in the secondary school. Both these systems allow for the new nature and structure of chemistry.

The strongest feature of the Nuffield Project is, in my view, the possibility it offers of a wide view and the provision of general principles rather than concise instructions in chemistry. This method, initiated in schools, proved to be efficient and is now also used in the universities.(28) Pupils taught by the Nuffield system, may not have a thorough knowledge of the facts but they display a considerable 'chemical intellect' and not merely a chemical one. It is beyond question that the interdependence of physics, chemistry and biology has never been so evident as in the Nuffield system. The essential part of the system is the physiochemical principles, e.g. thermodynamics closely related to the energy of chemical bonds and electrochemistry; chemical engineering firmly based upon physical chemistry and presented as an outcome thereof. The law of periodicity, structural chemistry and reaction mechanisms form the principles of chemical teaching. On the basis of the Nuffield system, one may talk about 'teaching through chemistry'.

The Nuffield system provides:
- a broad outlook on the natural sciences;
- development of the ability to propose hypotheses and to draw conclusions;
- discussion of difficult problems and methods for solving them.

As Piaget has observed (29): 'The goal of education is not to increase the amount of knowledge but to create possibilities for a child to invent and discover, to create men who are capable of doing new things'.

The above considerations indicate that integration within chemistry and its real integration with other related sciences, should be reflected in the teaching process both in the universities and secondary schools. This is a prime condition both for good teaching results today and for development in the future. The teaching process must be a true reflection of the chemical sciences, and must be closely integrated with its changing structure.

CONCLUSION

Various conclusions may be drawn on the basis of previous deliberations and discussions during the ICICE held in Wroclaw. It is obvious, for example, that the major change in the nature and structure of chemistry has been a considerable breakdown of the barriers between the traditional divisions of the subject, and this breakdown should be reflected in the teaching of chemistry:

1. The general chemistry course at the start of chemistry studies at university level should introduce elements of quantum chemistry, thermodynamics, kinetics.
   This allows a proper understanding of the electronic structure and the periodic system. It should give the theory of bonding and molecular structure and provide students with a basic knowledge of the chemical elements and compounds.
2. Education in modern chemistry should have a sound mathematical basis but questions relating to the teaching of mathematics - how much, how soon and of what kind - must depend on the individual character of the university.
3. The changes in the nature and structure of chemistry bring about a decreasing emphasis on predominantly descriptive aspects and an increasing emphasis on more theoretical aspects.
4. Theory should be closely connected with experiment, so as to help in the solution and explanation of concrete problems.
5. Consideration should be given to new physical methods and the appropriate division of science through minicourses: in spectroscopy, magnetochemistry, dielectric methods, electronic and nuclear resonance, etc.
   These methods should be applied to the solution of concrete structural problems. A separate course of X-ray diffraction should be introduced. It is also necessary to teach students the application of computers to chemical studies and to teach them to handle computers freely.
6. Potential advantages of new programmes include the enthusiasm of students and a more functional, operational approach to the study of chemistry. Potential disadvantages include loss of the initial enthusiasm and, almost certainly, a greater investment of faculty time. They may also require a faculty member to teach across his own subject boundaries.
7. Up-to-date material in inorganic and organic chemistry should be selected. The most important divisions should be introduced in the form of courses, e.g. transition metal chemistry, complex compound chemistry

(coordination chemistry), non-transition elements chemistry, chemistry of metalo-organic compounds, chemistry of heterocyclic compounds, chemistry of aliphatic, aromatic, alicyclic and other compounds. Physical chemistry as taught currently should be replaced by separate courses in thermodynamics, kinetics, electrochemistry, etc.

8. A broad course in structural chemistry should be introduced and integrated laboratories for students in structural chemistry, comprising problems of the whole of chemistry, should be established.
9. The scope of classical chemical analysis should be limited and replaced by broad teaching of the methods of instrumental analysis.
10. Biochemistry and biophysics should be broadly considered in chemical studies, e.g. as part of a study of complex systems.
11. The teaching of basic, modern chemical synthesis should be integrated with modern research methods. Laboratory work should introduce specialization on the basis of a broad approach.
12. New techniques of teaching in some universities (e.g. audiovisual teaching, computer programming) should be tried out.
13. We should give up the good lecture as the basic form of instruction.
14. Seminars should be used for small groups, beginning from the first year of studies. Lectures should be related to seminars and other teaching situations to improve the self-confidence of students, e.g. seminars, parallel with lectures, for which the students elaborate the problems with the help of the literature.
15. Industrial chemistry should be taught in the modern way, on the basis of chemical engineering. The latter should be directly connected with thermodynamics, kinetics, and other fields of chemistry, as their consequence. Students should learn how to make the transition of a process from the laboratory to the industrial scale.
16. Non-chemical 'packages', e.g. economics, a foreign language, chemical education, etc., should also be offered in association with the chemical packages, the student being largely free to choose a 'mixture' to suit his personal interests and abilities.
17. The secondary school should offer the possibility of well-learned chemistry and awaken an interest in it, through acquaintance with the divisions and abilities of chemistry, without the accumulation of unnecessary details. The secondary school should present a broad picture of chemistry and its connexion with other natural sciences. Laboratory work (performed by students as independently as possible) should teach self-confidence in the planning of one's own work, independent understanding and the solution of problems.

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The changing characteristics of students*

by Ariel H. Guerrero

METHODS OF ANALYSIS

The main method of analysis for this subject seems to be the questionnaire, including tests and measures, applied to different samples: national institutions, students and graduates, teachers and professors.(1 to 21) Surveys by experts are not so common (22, 23) and even observations (direct, film, TV) of individuals and small groups, or interviews with a structured but relatively free dialogue, have been less used, in spite of their applications in other fields. Statistical methods are standard for the interpretation of data.

An important point to remember is that students' opinions and behaviour are generally reported by adults and this mediation is almost impossible to escape, not only in respect of the output as data and results but also at the input level, through transmitted cultural patterns and propaganda. It is very difficult to detect these influences as separate factors in the characteristics of students, but it seems advisable to listen directly to the students themselves, preferably those who are mature and those who have already got their degree in chemistry or in non-science subjects. Professional associations could be used to organize consultations with the latter.

DISCUSSION OF FACTORS

Using a broad interpretation of the word factors, we have classified them in two groups: (a) the personality of students in relation to learning science; (b) general factors in their background and previous training.

Personality of students in relation to learning science

If we consider the high proportion of the relevant literature which suggests a revulsion of students from science in some countries, it is difficult not to be alarmed. But if we inquire into the contents of those papers, the situation is seen to include different nuances. (24 to 28)

Grounds for alarm may be found in some representative phrases: the most capable students are no longer choosing college majors in the physical sciences and universities lower their admission standards for science applicants, in comparison with those applying for social science and the arts; we, as chemistry professors, have asked the student to do too much, too fast, too soon, and we have asked him to keep at it too long, we have looked at the student as a statistic; improved teachers, courses and equipment are not enough; the theme of this rebellion is that science is an inhuman discipline, the fruits of science are seen as pollution, toxic drugs, chemical warfare and the nuclear bomb; science has modelled high school curricula after science itself and its role in the university; science is a necessary evil.

Let us consider a few questions:

- Do students entering high school know what science really is?
- How does early specialization and choice of subjects affect students' decisions about their careers?
- How does the term physical science impress the students, as an image of chemistry?
- If the humanities are one of the domains

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* Because it would have been very difficult to cover the complete field, attention has been focused on the characteristics of students at the age of university entrance (about 17), while keeping an eye on the transition from undergraduate to graduate. This did not exclude the treatment of other levels. The requirements of each section of this paper were interpreted flexibly.

of culture, does this imply that the other domain, where chemistry is located (science) should be called the inhumanities? (anti-humanities? non-humanities?)

Some answers are suggested in the same papers: the high school students have somehow developed an inaccurate image of science and the scientist; re-examination of the presumed need for science students to begin specialized study early is surely in order; that a young man who plans to major in any branch of science has to make this weighty decision while still a high school senior is patently absurd; there has been too much emphasis by counselors and teachers on the difficulties of science courses and excessive stress on the college-preparatory function of science courses in high school; a major purpose behind change in science curricula and teaching methods was to influence the career choices of youth; the students resent governmental manipulation of the curricula accomplished by means of financial incentives for the purpose of meeting national manpower needs. Biology, social sciences, psychology and economics are the beneficiaries of the rejection of physics and chemistry.

Low enrolment in agronomics and veterinary science has appeared in some agricultural countries and offers a hint that market demand is not by itself an exclusive factor in career election. It would seem that some lectures, with films and debates, led by first-class professors and teachers (missionaries) during the two years before the decision between science and non-science must be made, might be a very effective method of attracting students. Science fairs prepared by university students and offering an opportunity for secondary students to exchange ideas and receive opinions from senior students, would be another interesting method. These two processes must point to a definite objective: recognition of chemistry as such, and of chemists as real people. The mass media should give a more exact and precise image of science and particularly of chemistry.

Another set of attitudes towards science is expressed along the line:(27, 28) the current emphasis on science requires humility and a sense of proportion (29) on the part of the scientific community but it is characterized by: (a) an overemphasis on basic science at the expense of applied science, (b) a mode of thinking which does not allow for human reflections or interpretations, and (c) valuing research over action. In developing countries, these criticisms are particularly stressed because to denigrate the applications of science in those nations is more than mistaken, it is lethal. On the other hand, some applied science faculties overemphasize applications and do not teach basic chemistry adequately.

The concepts of integrated science have been permeating through secondary school to university level.(30) Intellectual and cultural partnership between disciplines should be encouraged through relatedness and interdisciplinarity and avoiding laminated courses: a layer of biology, a layer of chemistry and a layer of physics. The key words to remember, from primary to higher levels, are: integrated, coordinated, differentiated but unified and interdisciplinary.

The problem of the two cultures is in the air as noted earlier in reference to the fact that humanities and inhumanities have both become disgraceful words. What does humanism mean? At least three concepts:

(a) a way of life and thought which is opposed to theism and which takes as its basic concern the self-realization of human beings, as the measure of all things and the centre of the cosmos; a doctrine defined as a philosophical school by Schiller during the 19th century;
(b) a secular movement started in Italy during the second half of the 19th century, originally representing Greco-Latin neo-classicism as a source of inspiration and a break with scholasticism.
(c) a popular name for such qualities as generosity, sympathy and kindness, more properly called humanitarianism.

The generalization of the second meaning was fatal for science because Galileo, and modern physics with him, was born one century after humanism; Lavoisier and modern chemistry appeared much later. Consequently both physics and chemistry were considered neither humanities nor, by popular consent, human. The splitting of the two domains of intellectual activity apparently originated in this confusion, and has its consequence in the increasing gap between the literary and scientific poles.

On the other hand, there has now developed a new wave that distrusts and rejects the very processes of reasoning and rational discourse. This type of anti-science is in the air we breathe today: science has been defined as anti-life (32) contemporaneously with the rise in parts of the world of subcultures of youth.

Of course, the reaction differs across the world, ranging from tumult and diminishing enrolment to neutral silence.(33) Perhaps it is too much to ask for a document written by young people, looking upon science as some of us did when we were students.

General factors in background and previous training

The educational system and curricula of a country are naturally important factors influencing both background and previous training.(34, 35) Of the other sociological and economic factors, family income has been studied fairly completely (36) in some countries, but references to political systems, cultural patterns and religious beliefs as factors affecting the characteristics of students are scarce.

It is recognized that education given before primary school is decisive and that if there are reasons which hinder pre-primary education, the first two years of primary school must take account of this situation.(36)

Availability of schools and universities is another important influence and measures have been taken to develop radio, correspondence and TV teaching.(37) Help by senior students in teaching younger ones is recommended at every level of education, especially for backward groups.

However, the main question is: who attends schools and universities? Statistical data provide some answers.(38) It seems that two important influences in some countries are family income and parents' education. Curative measures, such as scholarships and levelling-up courses, may be adopted to extend opportunities to low-income and backward cultural groups, but the emphasis must be on planning prevention because in education remedies work only for the survivors and the original total population is lost.

In some countries, according to a specific scheme related to the needs of the State, the student population reflects the composition of the whole population so that family income is not a main factor and parents' education is not relevant in the students' choice of career. It should be borne in mind that in certain countries science is regarded as a neutral description of facts and their relations, neither good nor evil in itself; similarly financial support is considered as a hint, not as a manipulation.

The creation of a climate by primary and secondary schools is directly connected with the cultural pattern in determining students' behaviour, values and beliefs. Many authors support the view that inspired teachers may be more influential than systems, techniques or even patterns; others hold that science is considered a difficult field, building resistances and prejudices against its choice (39) because enrolment in high school is probably linked to achievement during the first years. The advice of counsellors and the quality of courses deserve more attention (40) as operative factors in attracting secondary school students to science.

Language is accepted as an important basis for the background of science students but more research work seems necessary regarding the influence of verbalization on achievement in scientific subjects.

Mathematics is the other base in starting and following a study of science. Socio-cultural prestige provokes ambivalency and controversial arguments about its value: most consider it important and beneficial but others see it as difficult and lacking flexibility.

On the other hand, for many people, chemistry's image is that of a natural rather than a physical science, and it may happen that for them physics has a better reputation as an academic subject. Similarly, some professors of chemistry are switching to bio-chemistry. The explanation of this switch may be related to the comprehensiveness of biochemistry, to its research activity, because things are happening there, and to the feelings of students who are convinced that biology is more directly connected with social demands than chemistry. Other professors of chemistry believe that some of the current teaching of biochemistry is not basic chemistry any more, but that in itself it may afford a strong motivation to pursue the study of chemistry.

The mathematization of science may be considered an accomplished fact, but the level and methods used to mathematize scientists - chemists in particular - deserve special discussion in terms of a detailed curriculum and coordination at each step, paying attention to the transition to modern mathematics. The management of this process may stimulate or inhibit the interest of students in science. An U.S.S.R. report by Professor Platé in the Survey of Chemistry Teaching at University Level illustrates the present position at a higher level.(41)

The methodology and structure of chemistry, which are the subjects of other chapters in this publication (papers by Jezowska-Trzebiatowska and Achmad) have, of course, a significant influence on student attitudes.

The absolute number of students entering university courses has increased practically everywhere; though percentages show diminishing figures for chemistry in several countries, they are not so acute as for physics. As we have said, the beneficiaries in those cases have been biology, social sciences and economics.

There has been much concern with the levelling-off or percentage falls in enrolment in most developed countries, but the only comprehensive investigation made (42) arrives at these general conclusions: the industrialized countries do not in general appear to be expanding their efforts in chemical education at any great rate, if at all; and the developing countries are in no position as yet to make really significant contributions on a world scale. For many years to come, the demand for people trained in the many branches of chemistry will increase as more countries develop and maintain chemistry-based industries, and as the technological basis of general industry broadens and intensifies. The limited data provided on schoolteachers suggest a falling off in the recruitment, and also probably in the quality, of the primary producers of one of the world's most urgent necessities: trained manpower. Judged by the light of expanding requirements, the world picture of chemical education since about 1961 is not encouraging: at best stagnation, at worst a decline sufficient to slow and even halt economic growth. If the past and the present are any criterion, a shortfall of qualified manpower in the developed countries will tend to deprive the developing countries of their own comparatively few and precious qualified people. It is no great contribution to the well-being of the world to provide university places for students from these areas if they are not encouraged to help relieve the pressing needs of their own countries. Instead of being net exporters of scientific and technological manpower to the developing countries, the industrialized nations are net importers from them, and this can only accentuate what will surely prove to be one of the most bitter causes of world tension in the future.

To explain these inverted trends in developed and developing countries as a consequence of changing characteristics of students seems rather awkward, since obviously a difference is involved in potential demand which stimulates a real surplus of chemistry graduates, based mostly on the effect of expectations in the developing countries.

Finally, the choice of career and work is a point of interest in detecting the attitude of students. The science-teacher image, even at primary school, is fundamental in that choice. About the profile of the young science graduate, (43, 44, 45) some countries show inherent aspects as well as others which are common to all chemistry departments.

WORKING HYPOTHESES

From the Renaissance and the great geographical discoveries, the discharge of energy and desire for adventure, perennial needs of youth, began to be satisfied at an early age, say around 15 years. Army and navy service, exploration and conquest, search for minerals and other resources, missionary work, were opportunities which attracted young people and allowed promotion to unprecedented numbers, sometimes of very humble origin. One may argue that the average expectation of life was under 40 in those days, but the fact remains that through such channels, and others, energy and the adventurous spirit, tinged with fantasy and ideals of youth, had available outlets. When this situation began to be reversed, when the possibility of action at an early age for adolescents became restricted through schooling, sports and controlled social relations, coincident also with the development of public education and the final establishment of secondary schools (19th century), Bohemian life in big cities had started to serve as a nucleation centre for young people.

An open desire for understanding and emancipation, a hidden appetite for philosophical explanation, can also be traced to about that age - demands which, if they are not given due attention, may find substitutes in slavery to a gang, superstition or exploitation by false guidance. Irrationalism, anti-science, indifference, unrest and rebellion may be connected with these trends, but we must also consider honesty, spontaneity and initiative, loyalty to the authentic teacher, stamina for effort in support of ideals, craving for a leader, instability and sympathy for change, freedom in thought and behaviour.

We must also remember a conviction which permeates society and which may be summed up in the phrase, 'education is a value which cannot be taxed or confiscated'. Added to rising living standards and population increases, these are the explanations for the higher numbers enrolling in universities everywhere.

The influence on education of historical factors, such as the Second World War and subsequent conflicts, and of social factors, e.g. co-education, taken for granted in secondary schools, has not been scientifically studied in connexion with the change of attitude towards science and the upheavals in the universities of some countries.

The problem is how to get an equilibrium or a steady state between all these forces and as chemists we can see that we must try to get a mild 'Le Chatelier psychological effect' into adults' actions. Schools with discipline, sports with norms and umpires, and controlled social relations consistent with moral order will add the stabilizing ingredient of freedom to the joy and laughter of romantic and bohemian life. What is disturbing is the spectrum of violence which must be checked at some point, if human and institutional disintegration are to be avoided.

The pressure of the population of young males mentioned by H. G. Wells as a fundamental factor in social and political changes, today stimulates in society (including, of course, young females) both beneficial effects (in some innovations and spontaneous actions) as well as disruptive ones (when it foments the generation gap and moral chaos).

Preaching and motivation will not be enough; love, sense of humour, intelligent knowledge, honesty and firmness seem to be the answer in education and elsewhere.

ISSUES AND CONCLUSIONS

We can now apply the Socratic-dialectical method to reconcile this information by asking:

- Is the term 'student' adequate when referring, nationally and internationally, to such statistically diverse groups?
- Are the changes in students' characteristics permanent and significant or are they relatively minor and transitory?
- How are these characteristics related to the process of science teaching-learning, particularly in chemistry?
- What can we do to improve conditions?

We assume from the start that the published conclusions cannot be generalized to the different regions of the world, partly because there is a lack of comprehensive data about most of them, and partly because in each country the kinds of schools and university departments are heterogeneous. Besides, it is evident that, without detailed supplementary explanations, we cannot compare data from countries with different educational standards and systems, especially those which have chemistry before physics (both being optional in high school) with others where physics and chemistry, in that order, are studied by every secondary school student.(46)

Some more specific questions may now be raised:

- Are the present content of chemistry and the teaching methods used appropriate for the bulk of students, from the very beginning of their rational life?(47) This question applies to every branch of science.
- Is the level of reasoning, qualitative and quantitative, correlated to the level of aptitude of most students at each stage?
- What are the adequate doses of verbalization, audio-visual aids, mathematization, and lab work required for the development of each subject and as a general strategy for attracting the student?
- How many answers and how many problems are there in each topic and course.(48) How much integration, coordination, unification, differentiation? How much historical approach, social implications, descriptive material and applied knowledge with enough human interest and scientific rigour, all simultaneously?
- Should teaching-learning methodology go on its way towards personalization under guidance and towards small tutorial groups, or must we try to combine the best of each approach including good lectures and standard average pacing?

With the sole purpose of launching tentative conclusions, some openminded suggestions are offered for the future.

1. We can contribute to channel positive and even negative characteristics of students through good teaching of science starting at an early age. Good teaching is relevant, plain, rigorous, imbued with human interest and social sensitivity; has a selected motivating content of basic principles, experimentation, numerical and conceptual problems and applied knowledge, introduced by means of scientific methodology training (process approach). The image would be education through science.
2. Integrated science may go from pre-primary to an age in which coordinated branches of science are differentiated as pedagogically convenient disciplines, when quantitative reasoning and abstraction powers allow a more mature perception of science (fourteen years old). Chemistry, if possible, after physics in this scheme; when specialization occurs at high school, some kind of reform is advisable to avoid premature irreversibilities in the choice of non-science subjects.
3. It must be stressed that chemistry is as humanistic as any other section of knowledge; that we cannot understand our world and our times without learning real, undiluted science with the required verbalization and mathematization; that there is in science enough of the spirit of adventure to satisfy all the range of personalities, from poets to soldiers; and that science and its applications are not evil by themselves but depend on the uses made of them through administration, management and politics.
4. Participation of senior students is strongly recommended, in teaching, in giving opinions about courses once approved, and in research work, as early as possible at each stage. Of course, abundance of jobs and financial support will increase attraction and planned quotas may direct the students, but these inventives are not free of the manipulating effect, which is not attributable to missionary teachers and professors who are sent to tell and show students what science really is, at the proper moment previous to their choice.

5. Harmony and equilibrium of the factors mentioned throughout this paper, coordination between mathematical and logical thinking with scientific results about the material world, will lead to education through chemistry, accepting Goethe's statement, 'To think and to do, to do and to think, is the sum of all wisdom'. With these objectives in view we shall convey to the student not only intellectual knowledge but also the tenderness of human communion in realization and creation, the love and stamina needed for survival in freedom and dignity, and the attitude of respect for, and an expectation of, justice from authority.

To face all these problems we must study factors, do research on situations and continually discover new solutions and go beyond the subject of this paper, interconnecting with other fields related to the responsibilities of our position as educators.

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RECOMMENDATIONS

1. The role which chemistry plays in industry should be intensified and taught at schools. The definition of what a chemical industry - or semi-chemical - is must be clarified on the basis of 'chemization' of industry.
2. To inform and give guidance for:
   (a) career choices
   (b) living in a technological age
   The activity of groups of 'missionary' professors and teachers, as vocational guides to students in secondary school should be expanded. Expertly made films and a standard booklet about 'What is Chemistry' would facilitate their task.
3. Science fairs and science clubs, directed by both students and staff, to provide training in the scientific method and to emphasize the importance of chemistry in daily life, should be encouraged.
4. Students' and young professionals' opinion about Chemistry teaching and careers should be consulted as an essential feed-back.
5. Involvement of senior students in teaching, when possible (for instance in laboratory work), should be encouraged.
6. Early active participation of students in research programmes should be extended.
7. Data and information about different models of students' characteristics should be collected from all over the world, considering that students change and develop in different ways according to social and political models.

Up-to-date and precise learning objectives in chemistry

by M. J. Frazer

INTRODUCTION

There are many models for curriculum design, (1) but the essence of them all is a cycle with stages of the type shown in Table 1. This paper is concerned with stages 1 and 2 (aims and objectives), but because curriculum development is a cyclic process these two stages cannot be isolated completely from the others. The words aims and objectives are sometimes used synonymously, but in discussing a curriculum it is usual to make a distinction.

Aims are the broad intentions of a course, whereas objectives refer to detailed specifications of the knowledge, skills, abilities and attitudes which should be possessed by the student at the end of a particular study. The difference between aims and objectives and the contrast with the traditional topic- or content-based syllabus is illustrated in Table 2.

Some authors replace the word objectives by other expressions, introducing finer shades of meaning. In this paper objectives will be used to cover any of the terms in Table 3.

The main problem with aims and objectives is that of the level of specificity. It is self-evident and uncontroversial that courses should have aims. However, when these are specified in a list, they often seem too broad and too vague to be of use in guiding either the teacher or the student. Many teachers still prefer the aims to be implicit rather than to be listed explicitly. This situation must be deplored. Nevertheless in an increasing number of institutions, in various countries, statements of the aims of courses in chemistry are being specified. Some of the factors affecting the selection of aims, and recent trends (implicit and explicit) in the aims of chemistry courses at secondary and tertiary level are presented in the next section.

Aims may be too general but, on the other hand, there are many who believe that objectives are too numerous and too specific to be of much value in education. A description of the attempts to define objectives in the study of chemistry, accompanied by examples, is given later and in the final section there is a critique of the use of objectives in the teaching and learning of chemistry.

Because some consider that aims are too broad and objectives too detailed, intended outcomes of courses are sometimes defined at intermediate levels of specificity, and expressions such as goals, intermediate aims and intermediate objectives are used by some authors. Intentions of chemistry courses so described are naturally included here. This

Table 1. The stages of curriculum development - a cyclic process

1. Decide the aims of the course 2. Specify the objectives	What are the students to learn?
3. Select the course content 4. Decide which teaching/learning method(s) to use	How can this learning best be achieved?
5. Specify the assessment method(s)	How can the extent of learning be measured?
6. Make a reappraisal of items 1-5	How much has been learnt and should 1-5 be altered or improved?

Table 2. The difference between aims and objectives

	Item from a typical content-based syllabus	Example of an aim related to this syllabus item	Example of one objective related to this aim
Example	Equilibrium	The aim of this course is to illustrate the concept of chemical equilibrium, and to present the relevant thermodynamics.	By the end of the course the student should be able to calculate the partial pressure of gas at equilibrium, given the gas phase reaction, the value of K_p, and the partial pressures of all the other components.
Comment	A single word does not convey to the teacher or to the student the level or emphasis required.	This gives more detail, but still does not make it clear what the student should be able to do at the end of the course.	To cover the topic 'equilibrium', many statements of this type would be required. See Table 10 for further examples.

Table 3. Words used to qualify or replace objectives

Ultimate goals
Behavioural objectives
Operational objectives
Performance objectives
Performance specifications
Learning specifications
Intended outcomes
Expected outcomes
Desired outcomes
Behavioural outcomes
Learning targets

Table 4. Factors affecting the selection of aims

Students	Their needs, aspirations and motivations. Their existing levels of knowledge and abilities.
Society	The requirements for trained manpower. The requirement for an "educated society". The costs (facilities and time).
Teachers	Their knowledge and abilities. Their acceptance of change.
The subject	Its values, knowledge and structure. Its changing nature.

paper is not concerned with how to achieve the aims and objectives, nor with how to assess whether they have been achieved. It is concerned with the methods and problems of defining aims and objectives, and with highlighting current trends. For general accounts of the problems of curriculum design, and of defining the intentions of courses there are many standard sources.(1 to 6)

AIMS

Why study chemistry? In the broadest sense the aims of chemistry courses (secondary or tertiary) are threefold:

1. to prepare students for professional careers in chemistry;
2. to contribute to a general education* using chemistry as a vehicle;
3. to inform future citizens of the nature and role which chemistry plays in everyday life.

At secondary level, the order of importance is $3>2>1$, whereas at tertiary level this order is reversed.

At any time in history in any particular part of the world factors of the type listed in Table 4 will have certain priorities placing more or less emphasis on these three broad aims. It is not implied that there are, or should be, three distinct types of course, nor is it implied that preparation for a professional career is not an education itself. In fact, this broadest division of aims is of little value in leading to selection of content or learning experiences. What is needed is a higher level of specificity of aims with the expectation that these will overlap the three broad areas.

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* General education might be defined as preparing for a full and useful life in contemporary society.

Secondary level. Courses in chemistry have always had aims, but usually these have not been specified in written lists. Often the teacher and the student have assumed the aims from the context of the educational situation. It may not be too cynical to state that at the school level the aims of many teachers was, and in some schools still is, to help their students pass an externally imposed examination; and the students see their aims in the same way. The aims become related to a content-based syllabus and to past examination questions. This leads to an overemphasis on recall of factual material.

In the last 15 years there have been several major developments of chemistry curricula at school level, mainly in the 13-18 year age group; (e.g. in the U.S.A., Chem. Study; and in the United Kingdom, the various courses sponsored by the Nuffield Foundation and by the Scottish Education Department).

These courses were all designed with the intention of improving learning both about, and through, science. There was much more emphasis on understanding and using science, and much less requirement for the recall of factual material. Finally these developments had in common the notion that students should gain an appreciation of the role of science in society and everyday life. These were the aims of the recent secondary level developments. The intentions, design and implementation of these courses are well known and have been well documented.(7) Similar developments have occurred, or are occurring, in other countries. For example changes in the system in France have been described.(8)

Internationally the most recent trends at secondary level are: (a) an even greater emphasis on the interaction of chemistry and society, (b) a belief that students should appreciate the interdisciplinary nature of science, and (c) the need to develop the individual.

The aim that students at all levels should have an understanding of the social purpose of science and should be both knowledgeable and concerned about the place of chemistry in society has been emphasized recently.(9) As far as the interdisciplinary nature of science is concerned, there is now renewed interest in integrated science courses, and the current position has been reviewed.(10)

A good summary of the current broad aims of chemistry courses at secondary level has been given by Thompson (11) (Table 5). This list was distilled from a study of secondary level chemistry curricula in 18 European countries. The survey was undertaken by studying relevant official publications from the countries concerned, and by a questionnaire. Information was gained on many aspects of courses, including much material on aims and objectives. This was summarized (11a) and the author produced a comprehensive list of objectives in the full report.(11b) The aims in Table 5 have been adopted for the chemistry course of the International Baccalaureate.(11c)

An attempt has been made in New Zealand to find an order of priority for the aims of school chemistry courses.(12) A questionnaire was sent to university teachers, teachers of students in the 16-18 age group, practising scientists, engineers, doctors, pharmacists, and second-year university chemistry students; and respondents were asked to give their views on the importance of aims (defined in the questionnaire) of courses for 16-18 year olds. An understanding of scientific concepts and relationships, and the ability to use the scientific method were considered to be most important, whereas little weight was given to the acquisition of skills, the application of knowledge or the philosophy of science.

A larger and rather more specific list of aims, or goals, including development of atti-

Table 5. Aims of secondary level chemistry courses (11)

1. To give the student such a knowledge of the framework of the subject as to enable him to understand the structure and changing of matter, under chemical conditions.
2. To make clear to the student the possibilities and limitations of such a knowledge, and to create in him an awareness of the impact and influence this knowledge has on society, so preparing him for life in a technological age.
3. To inculcate in the student a critical attitude with theoretical speculation based on experimental facts and subject to change, together with the ability for precise formulation of thought.
4. To develop in the student those manipulative and experimental skills necessary to make him competent and confident in the investigation of the materials around him.

Table 6. Goals of a particular high school chemistry course (13)

Students should:

1. Acquire an understanding of the basic generalizations and hypotheses of chemistry.
2. Become inquiry oriented.
3. Understand and use the method of science.
4. Appreciate science for its intrinsic value and contributions to society.
5. Be able to apply their knowledge.
6. Know the flavour and zest of scientific enterprise.
7. Develop and maintain a continuing curiosity and desire to know.
8. Recognize and conduct honest and unbiased evaluation of data.
9. Enjoy generating new knowledge.
10. Respect and consider the ideas of others.
11. Be flexible and open minded.
12. Learn how to learn.

Table 7. Generalized list of aims of chemistry courses (15)

1. To develop and sustain an interest in science and in chemistry as a central, supporting and challenging area of study.
2. To develop a working knowledge of, and favourable attitude towards, scientific methods of investigation, using chemistry as an example.
3. To encourage the exercise of curiosity and creative imagination, and an appreciation of the role of such speculation in the selection and solution of problems, the construction of hypotheses, and the design of experiments.
4. To develop the ability to see, and the habit of looking for, inter-relationships between individual phenomena, principles, theories, philosophies or problems.
5. To develop an appreciation of scientific criteria and a concern for objectivity and precision.
6. To develop an understanding of the fundamental and unifying principles underlying the behaviour of atoms, ions and molecules, and an ability to apply these principles to real problems involving materials in various physical and biological conditions.
7. To develop the skills, knowledge and habits required for the safe, efficient and thoughtful manipulation of chemicals and apparatus in common laboratory procedures.
8. To develop confidence and skill in the quantitative formulation of problems and in the treatment of data.
9. To develop in the student the ability and predisposition to think logically, to communicate clearly by written and oral means, and to read critically and with understanding.
10. To promote the student's understanding of the significance of science, technology, economics and sociological factors in modern society, and of the contributions they can make to improve material conditions and to widen man's imaginative horizons and his understanding of the universe.
11. To encourage the applications of chemical knowledge and skills to problems which are of importance to the community, in particular the optimum use of natural resources.
12. To provide an opportunity for the development of the student's motivation and social maturity, including an appreciation of his own limitations in relation to a career choice which will be fruitful to himself and to society.
13. To develop the student's understanding of the structure, values and procedures of the chemical industry, and the chemist's professional role in such a situation.
14. To develop knowledge of, and familiarity with the use of, important sources of chemical information.
15. To make the student aware of the limitations of his disciplines and their methods and to provide opportunities for him to understand, make and criticize value judgements.
16. To cope with individual differences in the abilities and interests of students, so as to ensure the optimum development of each student's potentialities for achievement and satisfaction.
17. To draw upon staff interests and expertise in such ways that the teaching is challenging and satisfying.

Table 8. Aims of a vocationally oriented chemistry course (16)

The intention of the course is that the student should develop:

1. A working knowledge of the basic principles of chemistry.
2. An ability to define and solve chemical problems.
3. An ability to work safely and efficiently in a modern chemical laboratory.
4. An awareness of the structure of the chemical industry including its major activities, raw materials, processes and products.
5. An ability to use efficiently the chemical literature and other sources of chemical information (including the ability to assess critically the value of results).
6. An ability to communicate both in writing and orally.

There are some aims which are more difficult to assess. These are that the student should develop:

7. An enthusiasm for chemistry.
8. A desire to know more about chemistry.
9. An appreciation of the value and relevance of chemistry to society.
10. An adaptable approach to new problems and ideas.
11. An ability to work in a team.
12. A readiness to strive for high standards of scholarship.
13. A concern that chemistry is used to good social purpose.

tudes as well as cognitive abilities, has been suggested for American high school chemistry courses.(13) (Table 6.)

This list is clearly ambitious, perhaps because it was produced by one person, unlike the aims from Europe and New Zealand which are distillations of ideas from many sources.

Tertiary level. Change at tertiary level has been slower than at secondary level. However, in several countries, during the last three years, due to the pressure of (a) a reduced student demand for degree-level courses in chemistry, and (b) changed employment prospects for chemistry graduates, tertiary-level teachers are beginning to question the purpose of their courses.

Several authors (14) have commented on the need to change the aims of chemistry courses at degree level. The opinion is frequently expressed that chemistry courses have in the past put too much emphasis on the content, and on the aim that students should be able to recall and use chemical knowledge; and insufficient emphasis on the aim of education through chemistry. The latter aim refers to students achieving skills and attitudes which are not only related to a career as chemist, but which can be used to lead a full life and to follow many types of career. It is all too easy to make generalized statements about the skills and attitudes of an educated person, but more difficult to translate these into explicit aims for *chemistry courses*, and even more difficult to translate these into objectives and/or into teaching materials and new approaches. Here we are concerned with current trends in explicit statements of aims of tertiary level chemistry courses. Three recent listings of aims summarize the position.

1. The first (Table 7) was produced by a group of chemists drawn from several institutions in the United Kingdom.(15) They have been careful not to specify whether their list is exclusive to tertiary level, and whether it refers to the preparation for a professional career as a chemist or to general education.

2. The second list, also from the United Kingdom (Table 8), is more limited and was produced by a working party (16) concerned with producing guide lines for the graduateship of the Royal Institute of Chemistry, a vocationally oriented course.

3. Panel III at the Snowmass at Aspen Conference (1970) (17) prepared a list (Table 9) of ideal characteristics of a chemist. This may be interpreted in terms of the intentions in respect of chemistry courses.

Other authors have stressed the need for: ability to communicate and use the literature, (18, 19) ability to select and achieve mean-

Table 9. Ideal characteristics of a chemist - a viewpoint from the U.S.A. (17)

1. Effective in applying chemical knowledge.
2. Concerned with the application of chemistry.
3. Sensitive to society's needs.
4. Personally committed to assist in solution of problems.
5. Effective in multidisciplinary problem solving.
6. Capable and willing to communicate to his fellow citizens.

ingful objectives;(18, 19) flexibility;(20) interdisciplinary interests, and appreciation of the role of chemistry in other subjects;(19) appreciation of the impact of chemistry on society;(21) and ability to make judgements.(19) In summary, recent trends at tertiary level place less emphasis on the factual content, and more emphasis on the acquisition of skills, abilities and attitudes expected not only of a chemist but of any educated person. There is also increasing emphasis on an awareness of the interaction of chemistry and society. These are the trends in statements of aims; there is still much to be done before they are widely implemented in courses. In addition, there is a gradually growing acceptance of the principle that more attention should be paid to the views of students when formulating the aims of courses. This is to be welcomed.

Chemistry for citizens. Science courses for the non-scientist have increased in importance in the last few years and the need to raise the scientific literacy of the public is now seen as a priority by many Government committees.(22) A number of authors have described these courses and some (23) have attempted to define their aims. These may be summarized as follows: to assist the overall development and maturation of the student; to show that science is a human activity and is part of a cultured person's world view; to provide an indication of the way scientists work by seeking relations between concepts and validating these by empirical tests; to instil an awareness of the profound and far reaching consequences of the uses and abuses of science; to show the historical continuity of the growth of science; to generate a liking for science, and to develop the facility for critical and unbiased observation.

In India one of the aims of science education is to train science-oriented managers responsible for technology transfer in the villages, involving problems such as fertilizers, pesticides, pollution, water resources, food and drugs, contraceptives, etc.(24) Much of the discussion at the Snowmass at Aspen Conference was about chemistry and society. Panel IV (25) which was concerned with Chemistry for Citizens, produced the statement: 'The objectives of the project are to promote public understanding of science as a human experience and to promote social responsibility on the part of scientists and science teachers'.

OBJECTIVES

Writing objectives. Defining objectives is not new, but it is only in the last 10 years that a strong movement in support of defining objectives has been prominent. Three reasons can be advanced for breaking down the aims of courses into specific statements of what is to be learnt (objectives). It is claimed that defining objectives: (a) gives direction to the teaching; (b) facilitates learning and (c) provides criteria for assessment. Advice on writing objectives is given in several books.(3, 5) The verbs in the statement should be as active as possible and should lead to a student performance or behaviour which is capable of assessment. The problems in writing objectives are to make sure that: 1. the objectives are consistent with the aims of the course; 2. all the aims are included in the list of objectives (it is all too easy to ignore the aims relating to high-level abilities and attitudes, and to include in the list only low-level objectives such as recall of knowledge and development of simple skills); and 3. an appropriate level of specificity is reached (if objectives are too specific the student may be antagonized by a long list of trivial learning tasks; on the other hand if objectives are too general, assessment of whether they have been achieved becomes difficult and the situation approaches that of providing a content-based syllabus). Each subject at each level presents its own problems, and the general texts on writing objectives are not of much value. For this reason it is probably easier for teams of chemists to work together in producing statements of objectives. De Rose (13) has written about defining objectives for chemistry courses.

Structuring objectives. A great deal has been written about classifying educational objectives into hierarchies. The classical books are by Bloom (2a) and Krathwohl (2b), but as these are written in general terms they may seem rather remote from the chemistry teacher in school or university. Other ways of classifying objectives have been reviewed (6, 26) and a classification in practical terms of degree-level physics has been described by Bears.(4) A simple scheme of classifying objectives under three headings may appeal to the average chemistry teacher.

1. Knowledge and understanding.
2. Skills - intellectual, e.g.problem defining and solving; - manual, e.g. handling apparatus
3. Attitudes

Recent efforts to define objectives. Four examples are described.

1. In 1967, the Curriculum Committee of the American Chemical Society's Division of Chemical Education embarked on an ambitious programme of improving the curriculum at high school and beyond.(27) Sub-committees were formed in order to deal with analytical, inorganic, general, organic, high school, physical chemistry; biochemistry, and the proper

use of performance objectives. Each sub-committee was asked to produce a written statement of the chemical topics with which a student majoring in chemistry should become familiar in his four years of undergraduate study and this to be accompanied by a list of behavioural objectives - statements of the activities which a student should be able to perform to demonstrate his grasp of a given topic. An outline of the programme was published (27) with an appeal for as many teachers as possible to participate. Some of the sub-committees have been more successful than others, but reports are now beginning to appear;(28, 29) usually only the topical outlines (i.e. subject headings of a content-based syllabus) are published, but copies of booklets consisting of lists of objectives are available from the chairman. An example of one page of objectives taken from the Equilibrium section of the list prepared by the General Chemistry Committee is shown in Table 10, in order to indicate just how specific the statements are. In all, the booklet from the General Chemistry Committee lists 358 objectives. Possibly the advantage of this exercise has been the cooperation between the teachers, and the analysis by the teachers of what they want students to be able to do. It is difficult to see how a list as long and detailed as this will be of much help to a student, or to a teacher who has not been involved in writing the objectives. This illustrates one of the problems of this approach to education. For the reasons indicated earlier, individuals find it difficult to write objectives, and much more progress can be made in a team. Teams composed of individuals drawn from many institutions can produce lists of objectives, but it does not follow that their less enthusiastic colleagues in a particular institution will readily wish to use their efforts.

2. The Open University in the United Kingdom provides courses at degree level by means of television, radio, summer schools and correspondence.(30) There is thus a considerable educational problem, and, from the start, courses at the Open University were designed by course teams consisting of educational advisers and technologists, subject specialists, and programmed producers. General aims of the courses are agreed and published, and for each course unit (usually about one week's work) a set of objectives is prepared and printed at the beginning of the course book. An example of the objectives of a course unit of the Foundation Course in Science (31) is reproduced in Table 11.

The use of objectives for degree-level courses has not been used anywhere else to the same extent. The materials and approaches of the Open University are attracting attention throughout the world, and as a result many more university teachers, including chemists, are becoming familiar with the use of objectives.

3. The need to develop lists of objectives is an essential part of the Keller Plan (Personalized System of Instruction) which has become very popular, particularly in the U.S.A. (32)

Table 10. Examples of objectives on equilibrium. General chemistry. Sub-committee of American Chemical Society (28d)

Equilibrium constants and equilibrium calculations phase equilibria (solid/gas)

1. Given a reaction and the physical state of each substance, write the equilibrium constant expression.
2. Given a reaction and the partial pressures of the gases involved, find the value of K_p.
3. Given a raction, the value of K_p, and the partial pressures of all but one gas involved in the reaction, calculate the partial pressure of the remaining gas.

Phase equilibria (liquid/liquid)

4. Given the numerical value for a solute of its distribution coefficient between two solvents, state the relative molar concentrations of the solute in the two liquids.

Homogeneous gas phase equilibria

5. Given a chemical reaction involving gases, write the algebraic expression for the equilibrium constant, both in terms of molar concentrations and in terms of partial pressures.
6. Given a gas phase reaction, the value for the equilibrium constant, and the molar concentrations of all but one of the substances present at equilibrium, calculate the concentration of the remaining substance present at equilibrium.
7. Given a gas phase reaction, the value of K_p, and partial pressures of all but one component, calculate the partial pressure of the remaining substance at equilibrium.

Table 11. Examples of objectives from the United Kingdom Open University (31)

1. Given the value of the heat of a reaction, decide whether the reactants are exothermic or endothermic.
2. Given the various bond dissociation energies involved in a simple reaction, calculate the enthalpy change for the reaction.
3. Distinguish between the enthalpy change for a reaction and the activation energy of the reaction by drawing a graph.
4. On a similar graph, indicate the meaning of activated complex.
5. Sketch (or select the correct sketch of) a reaction co-ordinate for a simple reaction of given thermicity.
6. Describe in qualitative terms how the energy can be obtained for thermal reactions.
7. Sketch the Boltzmann distribution and indicate how it changes with temperature.
8. Relate the changes in the Boltzmann distribution to the way rates of reactions vary with temperature.
9. Sketch (or select a correct sketch of) the variation of concentration with time for reactants and products in a reaction.
10. Define the rate of a reaction.
11. Relate the rate of a reaction to a plot of concentration against time.
12. Given the stoicheiometry of a reaction, write the various expressions for the rate of the reaction and determine the relationship between them.
13. Given a table of concentration as a function of time for a reagent, determine an initial rate for the reaction.
14. Suggest (or select from supplied suggestions) possible rate expressions for simple reactions given their stoicheiometry.
15. Given a (simple) rate expression and the rate data (as in Objective 13 say), determine the rate constant for a reaction.

With the trend for more individualized learning, defining objectives will become more widespread. An interesting example is the use of behavioural objectives as an essential part of a programme of independent study in a U.S.A. high school.(13) A feature of this programme is the use of a hierarchy of basic objectives, optional objectives, and objectives that students develop for themselves.

4. A number of institutions and individual teachers have produced lists of objectives for their courses. Some of these efforts have been reviewed (33) and others can be found in the original papers.(34)

CRITIQUE OF USING OBJECTIVES

Much has been written in favour of, and against, the procedure of defining objectives, and occasionally the debate seems to be more emotional than rational. It is necessary to consider two levels: (a) opinion (albeit opinion expressed logically and on the basis of classroom experience) and (b) experimental studies.

Advantages

1. The student is clear what he has to achieve. He does not have to guess from the syllabus, from the course content or from past examination questions. He can concentrate on learning. Even more fundamentally, he can decide whether the course of study is what he thought it was from the title and whether he needs to enrol.

2. The teacher is forced to think about what he wants the students to learn. Objectives are an aid in planning. This is perhaps the greatest advantage, because so often, particularly at the tertiary level, due to other pressures, teachers do not give enough thought to what they want their students to learn.

3. The teachers and students are in harmony. There is no confusion about what each is trying to achieve. The student is clear when incidental or illustrative material is included in the course.

4. The course content and the teaching and/or learning methods are more easily selected.

5. Objectives can be made the basis of individualized instruction.

6. The assessment methods are defined by the objectives. There is no problem of what to put into the examination. It is also possible to evaluate the success of the teaching methods.

Disadvantages

1. Education is not training; and there are many desirable outcomes of education which cannot be expressed in terms of changes of behaviour or terminal performance of the students. This applies particularly to the affective domain.(2b) Furthermore education is a subtle

process, and some of the effects of education may not manifest themselves for some years after a course is completed.

2. It is easier to write objectives for low-level abilities (e.g. recall of knowledge, simple manipulative skills), and consequently in any list the higher abilities tend to be neglected.

3. Individual students will exhibit different behaviours as a result of experiencing a course of study. Students should be free to derive what they will from their studies.

4. Objectives are either so specific that they appear trivial as a 'target' for learning; or, if less specific, the meaning is not clear and they might just as well be replaced by a topic list of a conventional syllabus.

5. A list of objectives even for a short course is very long and the student becomes confused and overwhelmed.

6. Students react unfavourably to the 'spoon-feeding' and 'brain-washing' which are implied by this approach.

7. Lists of objectives do not reveal the structure of knowledge in any subject, and the interaction between parts of the body of knowledge.

Summary of opinion on the use of objectives. There is no space for a fuller discussion (35) of the merits (5) and problems (36) of the objectives approach. An amusing attack on the use of objectives for education as opposed to training has been published in the U.S.A.(37) Recently Macdonald Ross (38) circulated a critical review and analysis of the position together with a useful bibliography. There is common ground in stating that for course planning, for giving direction to teaching and for detailing criteria for assessment and evaluation the objectives approach is accepted and certainly no one has been able to suggest an alternative. It is when claims are made that defining objectives assists the learning process that agreement vanishes. It is just this area in which experiment is required.

Experimental studies on the use of objectives. There are formidable problems in designing experiments to test whether learning is enhanced, and it is unlikely that there will be a definite answer from experiments covering all subjects and all levels and types of learning. The present position has been reviewed.(39) It appears that there are about an equal number of research reports indicating that learning is, or is not, enhanced by stating objectives. The various experiments are critically examined. In chemistry there have been only a few investigations. Boardman (40) found that there was no significant difference in achievement between a group of remedial chemistry students which was given objectives and a comparable group which was not. Heron (41) conducted a study with freshmen enrolled in chemistry courses. There was some evidence that students who received a list of objectives before the course, performed better in the final examinations than those who did not. However, there are alternative explanations, which illustrate the difficulty of experimental design. Some of the benefits may have resulted from the fact that graduate teaching assistants also received the list of objectives.

SUMMARY

At secondary level the trends are: (1) to illustrate the interaction of chemistry and society; (2) to develop the individual; and (3) to emphasize the interdisciplinary nature of chemistry.

At tertiary level a consensus is emerging that there should be less emphasis on the factual content of courses, and more attention to (1) understanding principles and their application to problems and (2) the acquisition of skills, attitudes and abilities expected of any educated person and useful in many diverse careers, not only in chemistry. Some lists of these aims have been given (Tables 7, 8, 9).

In common with other subjects there has been great activity in defining objectives. However, the production by working parties of long lists of objectives is unlikely to influence other teachers.

There is no strong research evidence that defining objectives enhances the learning of chemistry; on the other hand there is no evidence that it is harmful.

RECOMMENDATIONS

1. All courses in chemistry at all levels should have written statements of aims. These should be known to the teachers and to the students, and the assessment must reflect the aims.
2. For some courses and for some approaches it is necessary to define precise objectives. Even when it does not seem essential, some teachers will find it helpful to define objectives and to make them known to their students. Furthermore in some situations it may be practicable to involve students in defining objectives.
3. Chemistry teachers at secondary and tertiary level need assistance and even instruction in formulating and using aims and objectives. Conferences and courses are needed which concentrate on this problem, and on the problem of achieving the right level of specificity for statements of intent to be translated into meaningful action in the classroom.
4. It is *recommended* that national and international agencies organize such conferences and courses, and also provide an advisory service to individual teachers and to institutions on the formulation and usage of aims and objectives.
5. It is not recommended that national and international committees formulating precise objectives to be adopted for all courses at a particular level be established.
6. It is suggested that more research is needed to determine the effect of defining objectives on the efficacy of learning.

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Better understanding of the psychological processes of learning chemistry

by V. Hofacker

COGNITIVE ASPECTS OF EDUCATIONAL PSYCHOLOGY

The ultimate goal of any science instruction is to achieve lasting comprehension of facts and the ability to recognize and solve problems of a manageable level of difficulty. This has to be achieved within the set space of time which the student can devote to the subject and within the limits of material and personal resources available to the teaching institution. Under these constraints educators are constantly searching for the condition best suited to the training of future professional chemists or citizens with an appreciation of the powers and limitations of chemistry.

The field of chemistry is wide, its fund of facts, concepts, and theories is constantly growing. Too little can be taught by discovery and problem solving; the frame still has to be set by introductory verbal instruction. But how much of its content has to be learned by rote? What is meaningful learning and how can it be fostered? These are the questions to be asked. Ausubel (1, 2, 3) suggests that meaningful learning takes place if incoming information can be connected in a meaningful and non-arbitrary manner (i.e. through the proper relations imposed by subject matter structure) to the particular cognitive structure* of the individual learner. He has proposed the use of advance ideational organizers** to initiate meaningful learning.(4)

In the years following Ausubel's proposition a great deal of experimental research has been done on the use of advance- or post-organizers. No clear-cut evidence for the advantages of pre- or post-organizers, as compared to non-organizers, has been found at all, as far as instruction in the sciences is concerned. The results of a recent, reasonably conclusive investigation (5) again showed that success depended much more on the subject's natural organizing capability than on the use of an organizer. The conclusion, however, is interesting: 'the subjects participating ..., as science students, already possessed the appropriate ideational scaffolding. Consequently they were capable of subsuming*** the learning passage without the help of external aids.'(5) Here it is hinted that the subject matter structure in sciences, if properly introduced, presents in itself the most efficient organizer.

Research from still another source leads towards the same conclusion. In their studies on models for memory and cognitive structure, Novak (6, 7, 8) and his co-workers describe learning by rote or meaningful learning in the following way:

> In this model, the memory is considered hierarchical in nature, i.e. arranged from higher levels of generality and abstractness to increasing levels of specificity... The relevant conceptual scheme in each area is suggested as forming an ideational framework to which relevant substantive ideas and information can be associated... It is suggested that in meaningful learning the chunks and bits of information are held in close association to the ideational framework... On the other hand, if a relevant, specific conceptual framework is not present, incoming information is learned mainly by rote, i.e. it

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* Cognitive structure means the arrangement of concepts, facts, principles, rules related to the particular subject matter in the individual learner's mind.

** An organizer is a framework or pattern presented to the student to facilitate the organization of new factual material.

*** Subsume means, to be able to show that given material is covered by rules, principles, etc. It also means to be able to classify information correctly.

> is embedded in isolated loci in the memory matrix and not in meaningful association with the existing conceptual structure. In the latter instance, the memory trace is subject to rapid decay and can be held in the memory store only by such inefficient mechanisms as overlearning or artificial associations... Close interrelationships may develop between relevant conceptual entities. As conceptual maturity grows, the number and strength of the interconnecting bonds markedly increases.(6)

There is, indeed, experimental evidence that meaningful learning facilitates faster acquisition and longer retention than learning by rote.(9) But does the quoted hierarchical structure of concepts in memory indeed match the concept's relations in subject matter structure? Experimental evidence reached by word association tests on physics concepts (10 to 13) verifies that relations in students' minds after instruction match relations between concepts in subject matter structure.

How then, since the conceptual structure seems to be important, can concept attainment be aided? An impressive number of psychological experiments on concept attainment has been reported in the literature. The concepts involved, however, are too simple compared to science concepts. Only very general advice can be extracted (14) and little as yet can be learned from this research regarding the teaching of chemistry.

In spite of that, one may expect that many of the psychological findings on the nature of concept attainment, concept growth and development could be transferred to chemical education. Their transferability, however, cannot merely be assumed, and should be the subject of careful and systematic investigation. The Working Group therefore recommended that Unesco should commission investigations on the applicability of existing theories of educational psychology to chemical education at different levels.

This raises another problem. If full cognizance is to be taken of general educational and psychological principles for the benefit of chemical education, workers in this area have to become more conversant with the nature of educational research and the concepts of educational psychology than is currently the case. The chemist committed to chemical education will have to bridge the 'communication gap' between himself and the psychologist, for it is only the chemistry specialist who can effect the translation of psychological principles from a general context into the context of his own subject. Some easily and readily accessible means of bridging the communication gap have to be developed. The Working Group therefore recommended that the Division of Science Teaching of Unesco should sponsor the distribution of reviews of current psychological experimentation as applied to instruction in chemistry, e.g. by incorporation into 'New Trends in Chemistry Teaching'.

It is agreed that the complex concepts used in science can only be grasped if the more fundamental concepts involved in the construction of a new concept have been thoroughly understood. To provide for this, Gagné (15) suggested the use of 'learning sets'* to ensure the proper teaching sequence. Gagné and his co-workers invented a structured learning programme composed of hierarchically organized learning sets to observe student's learning of a mathematical schema. The study revealed that learning each successive learning set was dependent on the mastery of prior sets.

The question, of course, remains whether a concept hierarchy established in this way will finally represent the true subject matter structure. In particular, whether parts of the concept hierarchy developed independently by this method will finally match. This seems to be an important question since maturing of the scientific mind may be regarded as identical to the process of establishing more and stronger bonds between the isolated elements of correct conceptual structure.

While, with regard to physics, much has been said concerning the existence of a concept hierarchy starting from fundamental concepts of high generality and low complexity to an increasing number of concepts of low generality and high complexity,(16 to 20) very little thought has apparently been given to concept relations in chemistry. So far, we can only state that common chemical concepts generally will be of higher complexity than physics concepts since object-phenomena relations in chemistry are more intricate.

Novak (21) has pointed out the need to develop a 'taxonomy of conceptual levels' analogous for example to Bloom's Taxonomy of Educational Objectives.(22) This, indeed, seems necessary. Novak suggested it could perhaps be done from the history of concept development and the ontogeny of concept learning by individuals. We would like to argue against the suggestion that the history of concept development might provide clues. As Kuhn (23) has shown by many examples, concepts (as we use them today) have not developed continuously but have undergone abrupt changes as paradigmata became obsolete. This fact shows clearly that subject matter structure can only be defined as that structure which the minds of the contemporary scientific community perceive. It also shows that this view is constantly, though as a rule slowly, changing. Thus, we would like to stress that a taxonomy of conceptual levels in chemistry has to be based on concept relations in established theories and on the hierarchy of theories. For educational purposes it has to take account of the ontogeny of concept learning by individuals.

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* A learning set might be defined as the pertinent subconcepts of a certain conceptual level in concept hierarchy. A learning set can be found by asking what a learner would have to know in order to learn at least the next set.

There is evidence that the conceptual structure of chemistry as seen by the specialist does not necessarily represent the best framework for the acquisition of chemical ideas and concepts by the student. Connexions and relationships between sophisticated chemical ideas recognized by the mature chemist are not infrequently beyond the student's ability because they are inappropriate to his intellectual and maturational level. It is therefore important to re-examine the conceptual structure of chemistry in an attempt to evolve conceptual schemes whose intellectual requirements match, and are compatible with, the intellectual capabilities of the maturing student. The concepts should, at the same time, be readily refinable so that the progress of maturation towards the 'correct' subject matter structure is not hindered. Particular attention should be given to the examination of those areas of chemistry which students find especially difficult and problematic and to the relative merits of alternative theoretical models from a point of view which is educational as well as (rather than only) scientific. The Working Group therefore recommended that Unesco should commission investigations on the conceptual structure underlying chemical knowledge and the relations of chemical concepts to each other.

In the sections which follow, some examples will be given of the implications of concept nature and level as well as of student maturity for the learning of chemistry.

THE CONCEPTUAL STRUCTURE OF CHEMISTRY

It has often been hypothesized that it is generally true that the concepts of chemistry can be constructed from the fundamental concepts of physics, even though some may not yet be defined in a way that relates them to physical concepts. An analysis of some of the most widely used chemical concepts, however, shows that the conceptual network of chemistry cannot simply be built from that of physics.(24) The concept molecule, for instance, can be defined in terms of fundamental physics concepts only as an isolated entity. As S. Golden (25) has shown, the concept molecule has no corresponding conceptual basis in quantum theory if applied to bulk matter or reacting systems.

Cyclohexane, for instance, is described chemically in terms of two different conformations, the chair and the boat form. In terms of quantum mechanics, both conformations are described by a single Hamiltonian operator and a set of stationary states. Let us consider the transfer of the energized molecule from one conformation to the other as an example of a chemical reaction, then the chemical question as to the rate of change of the concentrations of both species makes physical sense only if the observer states by which observable (i.e. measuring device) he chooses to identify the two conformations. The chemical concept of molecules in a reacting system can therefore not be formed within the net of physical concepts since a molecule must be identified by a measuring device invented by the experimentalist and its concentration is represented by an expectation value (i.e. a number), which obviously cannot be part of any set of fundamental physics concepts. This shows that even chemical concepts which seem to be well defined in terms of fundamental physical concepts, under certain aspects, cannot be related to fundamental physical theory.

In other cases, however, we can trace a complex chemical concept in its full meaning through a hierarchy of theories. In the case of the concept 'chemical equilibrium' we may describe the chemical equilibrium of macroscopic phenomena in terms of theories indicated in Table 1. In this hierarchy of theories, the fundamental equations of the more condensed description (Uhlenbeck, 26) are the result of a theoretical development on the level of the more fundamental description. In order to show this more clearly, brief characterizations of the different theoretical approaches have been included in Table 1.

On the level of 'thermodynamics', systems with which chemists normally deal can be handled without reference to molecular or atomic behaviour. Proceeding to the level of 'ensemble mechanics', we reach the fundamental concepts of physics and, in this case, have shown how a certain concept of chemistry emerges as a highly structured logical relationship between the fundamental concepts of physics. The description at this level, however, is not suited to the complex systems a chemist usually deals with. Our example may therefore serve as an amplification on the meaning of the adjective 'complex' with respect to the concepts of chemistry. The concept 'chemical equilibrium', as expressed in terms of thermodynamics alone,

Table 1. Tracing the concept "chemical equilibrium" through a hierarchy of theories

Complexity	Theory	Characterization of systems by
↑ allows for increasing complexity of systems to be handled ↓ uses less complex and more fundamental concepts	Thermodynamics	State functions
	Statistical mechanics	Distribution functions, partition functions
	Kinetic theory	Time dependent distribution functions, e.g. solutions of Boltzmann type transport equations
	Ensemble mechanics	Time dependent representative densities in phase space, reduction of densities yields distribution functions
	Mechanics	Representative point trajectories, ensemble averaging over trajectories yields representative density in phase space

does not contain all information present in the more fundamental theories. In terms of 'subject matter structure', however, the information is there, because here the concepts of thermodynamics are seen in the light of the relationships the hierarchy of theories sheds on them.

Extending our line of reasoning, it can be stated that some concepts used in chemistry are 'fundamental' in the sense that they grow out of the fundamental concepts of physics. But only in some areas of chemistry are these fundamental concepts sufficient to deal with the observed phenomena. In dealing with systems of higher complexity, more complex concepts have to be used which we call the 'basic concepts of chemistry'. They are of wide applicability to chemical phenomena. Examples include: chemical species, reaction mechanism, structure, conformation, stoichiometry. Without basic concepts, chemistry cannot be brought into a manageable conceptual framework. The complete understanding and proper use of this class of concepts, however, still depends on grasping their aspects related to fundamental concepts of physics and chemistry as well as to their intuitive chemical implications.

CHEMISTRY AND MEANINGFUL LEARNING

Fundamental as well as basic concepts of chemistry possess the high level of generality and abstractness of concepts which serve as first gates leading into the different channels of memory structure. Their organizing power grows as they become related to an increasing number of more specific concepts. The goal of instruction is to connect these concepts in all possible ways provided by subject matter structure. That this goal cannot possibly be achieved during the period of formal education is of no consequence for instructional purposes, since we hope that the learning process (i.e. the formation of more connexions and the re-evaluation of concepts associated with this process) will continue through the individual's lifetime. But since the learner's notion of a concept changes with experience (because the concept is defined by its relations to other concepts) formal instruction has to make sure that concepts are introduced in such a way that maturing (formation of more connexions in agreement with subject matter structure) is not hindered.

Two main lines of instruction can be perceived which are of importance to the correct mapping of subject matter structure in the cognitive structure of the mind. One proceeds from simple fundamental concepts (of physics) along the line of established theories to the more complex fundamental concepts of chemistry. The concepts so formed are well defined with respect to physical concepts of atomic and molecular behaviour but they are deficient in their relations to chemical phenomenology. These connexions can be readily made. The other road starts with the introduction of fundamental and basic chemical concepts in a restricted or approximate sense while from the beginning establishing relations to the chemical phenomenology. The instructional process then proceeds via concept refinement as more and more relations are established to the more fundamental concepts which are used in dealing with atomic and molecular behaviour. The stages of concept refinement have to be carefully planned, so that proper connexions to the fundamental physical theories can be made.

What are the merits and the shortcomings of the two paths? The first line of instruction is of recent origin. It is connected with our changing view of the structure of chemistry originated by the incorporation of physical concepts into chemistry. Let us begin then by asking whether it would be feasible to teach chemistry by starting with a relatively small number of fundamental physical and chemical concepts, building their network of relations slowly and carefully until one arrives at the well defined concepts of chemistry and their links to chemical phenomenology. Proceeding from this, the students could be introduced to the basic concepts of chemistry and trained in their proper use. This procedure would be advantageous because it assures the matching of cognitive patterns in the student's mind with the patterns of subject matter structure. At the same time, correct categories would be provided for the filing of chemical facts before confronting a student with them. Is this an ideal situation in view of Ausubel's theory? Should it be done, and could it be done, in those areas where the links between complex chemistry concepts on the one hand and fundamental concepts and theories on the other are particularly well established? (e.g. the periodic system in the spirit of atomic theory, chemical bonds or spectroscopy in the context of quantum mechanics, chemical equilibrium or entropy on the basis of statistical mechanics, etc.)

A close look at the theoretical framework proves that this procedure is inappropriate in general education beginning in childhood. Piagetian developmental psychology (27, 28) shows clearly that the stage of abstract logical operations necessary to handle the highly abstract and formal logical operations needed to proceed from fundamental theory to the level of chemical phenomenology, could never be reached before adolescence. As experimental research shows, even the learning of chemistry concepts by the use of simple models strongly depends on age and IQ.(29 to 31).

Concerning the chemical education of students entering university, should this begin with fundamental concepts and rigorous theory? The answer of course depends on the character and extent of instruction received in school. Even though IQ is stabilized at the age a student enters university, grave doubts arise if he possesses little previous knowledge. The only link between a new student and chemistry is the reality of chemical phenomena. It is a first source of motivation in the sense that the state of being motivated is one in which questions arise in the student's mind which need to be answered. But preliminary and crude explanations can, in most cases, not be given within the frame of fundamental concepts. For a long time the student will not be able to perceive the topics in which he is being instructed as part of chemistry. Any instructor of introductory chemistry courses has observed the frustration resulting from this treatment. In terms of Ausubel's theory, the first concepts a student is introduced to in this educational procedure are no help in the organization of chemical observations. Their effect on meaningful learning of facts is nil until the concepts can finally be presented in operational form. Only after the concept of outer shell electrons has been deduced from atomic theory, is it possible to introduce the periodic system of the elements as a good organizational framework for chemical properties of the elements. This requires a long chain of introductions, starting from the elements of wave mechanics and ending at the periodic table. Some educators have nevertheless chosen this path because they felt that only in such a way could concepts be shown in their proper relationships. Benefit is derived from the introduction of models as systems of manageable difficulty in the realm of theory. The relations between models and reality are seen much more lucidly at an early stage of instruction than in the course of the alternative line of teaching. The serious drawback of the method lies in the fact that the need to develop an adequate theoretical framework may not be obvious to the student. Thus the acquisition of the necessary techniques may seem to him to be a meaningless exercise. Even the best presentation may not be able to overcome the resistance due to lack of motivation.

What are the shortcomings of the alternative path? What are the dangers encountered in starting from concepts of immediate applicability for phenomena, regardless of whether they are fundamental or basic concepts? Chemical phenomena, though observed on the macroscopic level, are explained by the behaviour and properties of atoms and molecules on the microscopic level. Therefore, chemistry brims over with concepts of wide applicability which belong to the microscopic domain. While casual observation of chemical phenomena on the macroscopic scale is, of course, possible and concepts related to the macroscopic properties can be formed prior to instruction in chemistry, this cannot be true for concepts belonging to the microscopic level. These concepts are new to any beginner in chemistry, regardless of age. According to Piaget's studies, concepts in new subject matter have to be demonstrated by concrete empirical objects. In chemistry the concrete object on the microscopic scale has to be replaced by a model. Concepts are then demonstrated by the use of these models.

The models used include simple scale models (e.g. molecular models) as well as simplified systems derived by constraints on the physical properties of the system (ideal gas) or simplification of the mathematical description (core-electron model for the electronic structure of molecules). While the model character with all its shortcomings due to simplification is evident to the instructor, the model is usually taken as the 'real thing' by the student because of his developmental stage. This mistaken identification persists longer than one would like to think. There is a tendency frequently observed, even with advanced students, to extend the use of a model beyond its limitations. Argumentation based on the use of a model severely restricts the range of possible interpretations.

The understanding of an unfamiliar process may thus be blocked by preoccupation with a not sufficiently refined model. This is especially obvious in discussions between students and fully educated scientists. For brevity's sake, discussions between scientists are worded in terms of models. But while the latter are fully aware of the complete conceptual stage of the model, conclusions drawn by students not yet familiar with these facts are based on the model as the 'real thing'. The resulting misunderstandings frequently lead to the demand that models should not be used before they have been derived from theory.

What can be done to avoid falso interpretation of models? Merely stating the simplifications does not help much. The discussion will usually end in the anguished question: now, is it this way or that? It can't be both! And while the teacher knows full well that it can be both ways, he will have to teach the simplified model as the real thing because otherwise the student will be unable to form even a crude concept. Even to point out the model character of molecular models in analogy to wellknown scale models, like those of airplanes or ships, is misleading since there is more to simplification in molecular models than a mere scaling down. To try to explain the model character of physical or mathematical models is even more frustrating because a normal chemistry student lacks any experience with constructs of this kind. Thus the concept necessarily formed in the student's mind has to be crude. Refinement of the concept usually proceeds along the line of demonstating that the crude concept, and therefore the model, does not agree with additional experimental findings. A new model is introduced and the refined concept shown to comply with the new experimental facts. In this procedure the concept is constantly expanded to embrace more and diversified experiences, while the student learns to relate different manifestations of matter to different models. Thus, by experience, he comes to know that chemical models are not true reflections of chemical reality but devices to press nature into a manageable form.

There are some cases, however, where concept refinement is hindered by the very nature of the models. They may prevent the student from realizing that he is still dealing with the same concept. The models used in the interpretation of closely related phenomena can be so different that he may not be able to see any relationship. Vibrational-rotational spectra on the one hand and electronic spectra on the other may serve as an example. The common concept should be the student's notion that spectra arise from transitions between stationary states of the molecule. The models used in the interpretation of the two phenomena, however, can be so different (oscillator rotor in one case, MO model in the other) that he may fail to see the unifying concept of a stationary state being defined by the electronic, vibrational and rotational states simultaneously. Since he feels that there should be at least some connexion, but is unable to form any with the simple tools (models) available to him, dissatisfaction and even resistance against the introduction of still another model grows. In this case again, the seeming incompatibility can be alleviated by regression to the fundamental theory. Once the theoretical framework is built, models are reconciled and subject matter structure is properly represented in the student's mind.

Up to now we have been concerned with the nature of the concepts used to describe behaviour on the microscopic scale and their link to chemical phenomenology. There exists, in addition, a class of concepts which are related to the macroscopic scale alone if their discussion is confined to a certain theoretical framework. These are the concepts related to thermodynamics (thermostatics) and to the thermodynamics of irreversible processes.

The concept 'chemical equilibrium' may serve as an example. The most general version of this concept, namely, that equilibrium has been reached if entropy is maximized or free energy is minimized, is usually not easily and obviously related to observable chemical phenomena. It is not in a convenient operational form. But once it is stated as the general equation for the equilibrium constant in terms of concentrations, mole fraction, pressures or activities, it has been cast in an operational form. In these versions it can already be used as a subsumer.*

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* A subsumer is a rule, law, principle or other classificational scheme that allows for the organization of facts.

Thus, teaching this concept usually starts with operational versions of chemical equilibrium. The point to be stressed here is that all operational forms, as for instance the general equation for chemical equilibrium, van't Hoff's equation or expressions for the temperature dependence of a vapour pressure, are equivalent to and derivable from the most general version. They are restricted versions of the same concept, in the sense that they are derived under well-defined conditions. They are not approximate versions of concepts and they do not depend on models. Of course, if the different restricted forms are introduced as related to different chemical phenomena they will provide good subsumers for these phenomena only. On the other hand, as soon as it has been shown that they can be derived from the general version of the concept, all concept relations are established and the concept can be used in its full and unrestricted sense. From then on it can be applied easily and without danger of misinterpretation, even to unfamiliar phenomena.

Thus, whereas approximate versions of fundamental concepts are placed on different conceptual levels according to a model hierarchy, or hierarchy of theories, the restricted versions of a fundamental concept are all on the same conceptual level, even though different learning sets, in Gagné's sense, may be found for their teaching sequences. The existence of different learning sets results, of course, from the difference in the phenomenological objects to which they apply.

There are not many pitfalls encountered in teaching these restricted versions, except for the fact that formalization and quantification of these concepts is frequently attempted too early. This is especially obvious where intricate calculations or derivations are encountered.(32) Care has to be taken that the concepts are well understood in their logical, qualitative relations to the other concepts used in a derivation and that the student can translate mathematical expressions into verbal statements. Otherwise the derivation will be learned by rote and will not contribute to the student's understanding of concept relations.(33)

Consistently recurring topic difficulties may result from failure to establish the necessary relations between different approximate or restricted versions of fundamental concepts, as well as from language barriers, encountered when handling formal statements. They may also depend on the stage of mental development (34) or the time allotted to the topic. All these factors have to be taken into account. But in the case of restricted versions of a fundamental concept there is still another difficulty to overcome.

The concepts of thermodynamics are well-defined within the framework of the phenomenological theory. Their connexion with the behaviour of atoms and molecules is made in statistical mechanics and kinetic theory. Chemists, because of their continuous use of argument on the basis of molecular behaviour, regard the concepts of thermodynamics as tools for the description but not the interpretation of chemical phenomena, as long as they are confined to the framework of the phenomonological theory 'thermodynamics'.

In terms of subject matter structure this is true. On the basis of thermodynamic relationships alone, the concepts of thermodynamics cannot be connected with concepts applying to molecular or atomic behaviour. This makes meaningful learning extremely difficult. But as soon as interpretation on the molecular level is attempted, concepts defined in the framework of the more fundamental theories (see Table 1) should be used. Since these cannot easily be incorporated, interpretations of the concept entropy e.g. as a measure of disorder, are invented, which remain meaningless if not exemplified by probability considerations including energetic as well as spatial aspects, or the concept is demonstrated by the use of models, as for instance in the case of the division of entropy in a configurational and a thermal part. In any event, the proper subject matter structure can only be built if these interpretations can be proven compatible with the concepts of the more fundamental theories (i.e. statistical mechanics or kinetic theory). The interpretation of entropy as 'missing information' seems much more promising in this respect but has, to our knowledge, not yet been tried on an elementary level.

The conflict is typical of those arising at the introduction of important but complex concepts: on the one hand, thermodynamic concepts, such as entropy, cannot be meaningfully related to a major part of chemistry concepts if no microscopic interpretation is given and there is therefore a definite psychological need for interpretation. On the other hand, this interpretation has to make use of concepts or models which are compatible with, or can be changed (by means of concept refinement) into, the concepts of the more fundamental theories basic to thermodynamics. Again the dilemma could be solved by beginning with the more fundamental theories, but this procedure can be expected to show all the drawbacks usually encountered where the teaching of chemistry topics begins with fundamental (physical) concepts and theories.

We will now try to summarize the results of the preceding arguments: In order to provide the proper conditions of meaningful learning in chemistry, the great subsuming power of basic and fundamental chemical concepts must be exploited and, at the same time, the building of the correct conceptual network must be ensured.

The correct conceptual network is well defined for those concepts which can be traced back to fundamental (physical) theory. In order to connect these concepts to observable chemical phenomena, they are introduced in an approximate version, linked to certain models. If these models are carefully chosen in such a way that they may be established within the framework of fundamental theory, all approximate versions of a concept can finally be shown to agree with the same concept as it emerges from fundamental theory (e.g. chemical bond). Problems connected with the seemingly incompatible nature of the models are overcome at that stage. Hence, before a given concept is introduced, an investigation must be made to determine whether it can be regarded as an approximate version of a fundamental concept, i.e. whether the models used to demonstrate the concept can be derived from fundamental theory. Models of this kind should be used in teaching chemistry.

On the other hand, chemical phenomenology is so complex that a great number of basic concepts are employed which cannot be connected (or only in certain versions) with fundamental theory (e.g. the concept chemical species). In order to exploit their explanatory and subsuming power, while at the same time making all possible connexions with the well defined network of fundamental concepts, the context in which they become compatible with fundamental concepts should be stressed. Investigation of concepts and models used in chemistry with regard to their relations to fundamental physical concepts and models has not proceeded very far but should be important for the establishment of concept hierarchy.

It may seem as if the problems discussed in the preceding pages have a bearing only at the tertiary educational level. This, however, is not so. It should be quite obvious that the complete system of science education has to be conceived in an integrated form, if questionable or simply wrong introductions of concepts at a low level are not to block progress on a higher level.

Discussion up to this point may have evoked the idea that restricted or approximate versions of fundamental concepts constitute most of chemistry's conceptual network. This is by no means true. There is a wealth of concepts of wide applicability and great subsuming power for which no quantitative relations can be established and which cannot be connected non-arbitrarily to fundamental concepts. These concepts are necessary and cannot be dismissed unless they are replaced by some newly formulated fundamental concepts of chemistry. Whether or not it is possible to reduce such ad hoc concepts to a form relatable to fundamental theories is an open question.

INSTRUCTIONAL METHODS

The wide range of phenomena and their interpretation on a molecular basis which constitute the subject of chemistry cannot be taught by verbal and written instruction alone. It is universally agreed that for example laboratory experience is indispensable, for only here can a notion of the multitude of phenomena and possible observations that cannot all be taught in rules, laws, and principles be obtained. But which instructional procedures yield superior results in chemistry?

During their discussions of this question, the Working Party recognized that no single all-embracing theory of learning exists at present which could serve as an adequate model for the development of chemistry courses. Many of the elements of curriculum and course design in chemical education will continue to be based on empiricism. Little is as yet known about the effect of different instructional procedures and practices on the learning behaviour of students with different psychological characteristics. Genuine progress towards the establishment of sound educational principles on which to base instructional procedures for chemical education can only be made through a systematic identification of what instructional conditions cause what type of learning outcomes and attitudinal changes in students. To achieve this should be considered an important long-term aim of chemical education research. Chemical education is in the fortunate position of having developed in recent years a large variety of curriculum projects in which many different instructional procedures and conditions are incorporated. These could form the basis of the type of major study suggested. The Working Group therefore recommended that the Division of Science Teaching of Unesco should initiate a comprehensive study and review of instructional practices in different curriculum projects, to see what psychological generalizations may apply to the results of different instructional procedures. Since the results may well differ with cultural background and ethnic groups, multinational experimental studies of the psychological aspects of teaching chemistry should be encouraged.

In the course of discussions on psychological characteristics of human beings, the Working Group also touched on the subject of chemical control of behaviour and felt that more should be known about this topic. On the one hand, these examples, when incorporated in the course of chemical instruction, might well emphasize the importance of chemical knowledge for the understanding of the life processes. On the other hand, more knowledge of this aspect might provide the basis for understanding certain natural limitations to induced behavioural changes. The Working Group therefore recommended that Unesco might commission a source book on chemical controls of behaviour, e.g. pheromones, mosaics, circadian rhythms and brain chemistry.

Among the efforts to provide for optimal educational conditions should also be counted those which aim at the prevention of possible limitations caused by lack of essential chemical substances during early development of the human body, especially the brain.

The Working Group therefore recommended that a study be made on the relationship between brain development and physiological conditions, e.g. dietary deficiencies.

CONCLUSION

What can be learned at present from research on science education?

Two reviews on research in science education, one covering 150 items published between autumn 1964 and winter 1969 on levels from first grade to college by M. Belanger,(35) and one presenting a review of 204 items on secondary level science between 1968 and 1969 by W. W. Welch (36) point to the same fact: only a very few crude generalizations can be abstracted and these are of limited applicability to the design of chemistry courses and programmes and can hardly be related to learning theories.

Belanger characterizes the problem of reviewing research in science education in the following way:

'The standard indices show that there is a relatively standard set of categories ("concept learning", "problem solving", "discovery learning", "critical thinking", etc.) for classifying learning studies. Each category might be thought to represent a closely bound set of ideas, but (further) problems emerge as one begins to read the studies...' The general reader would probably like to know whether or not the research on discovery learning (an example previously chosen by Belanger) in science leads to any trustworthy generalizations. Even if impeccable research designs are found in the studies - and since this is rarely the case it becomes all too easy simply to describe and then tear apart the studies on technical grounds alone - can it be asserted on the basis of X and Y studies (examples from different subject areas and procedures quoted by Belanger) or 30 other variations, that 'discovery learning' is superior to some other variety of learning? What is the status of the construct discovery learning? ...

Thus the dilemma facing a reviewer of learning studies goes beyond identification, critique and generalization and extends to the nature of the learning categories themselves. A modest probe into the meaning of these categories immediately leads to difficult philosophical questions about the nature of knowledge and knowing.

With respect to the textbook definition of learning as 'change in behaviour' and learning theories, Belanger says:

'The conceptualization of learning in this way could be used to subsume studies in evaluation ... or studies in attitude change or any study where achievement is measured. However, if an attempt is made to narrow the range by adopting a notion such as Ausubel's Meaningful Verbal Learning or Piaget's notion of learning, in the broad sense, as simply another term for intelligence, then very few studies in science education could be identified as within either domain.'

Furthermore, with respect to the poor design of many of the studies, Welch states: 'Much of the work appears fragmented and uninspiring with little impact in the schools. Perhaps this is due to the fact that motivation for most of the work is completing some external requirement, a thesis or funding report, rather than generating knowledge about the educational process. This hypothesis is supported in some sense by the quality of work that appears in a few places that have ongoing research projects associated with them. There is hope for educational research only when experienced researchers are able to devote the majority of their time to seeking the answers to important educational questions.'

Welch's statement is supported by his finding that of the 204 studies reviewed more than one-third were dissertations, and one-sixth were non-journal articles. In this connexion he remarks that 'this suggests that more than half of the total science education research effort is either an initial research undertaking (dissertation) or a non-published report.'

With respect to chemistry as the subject of science education research, the compilation shows that only about 10 per cent of the studies (20) dealt with chemistry subject matter. Half of them were concerned with evaluation of the CHEMStudy programme.

These quotations may serve to indicate why so very little can be said at present about the psychological processes in understanding chemistry on the basis of research in science teaching.

The reasons that we have dealt so extensively with the conceptual structure of chemistry in this paper are, first of all, because of its relatability to existing learning theories (this includes the hope that knowledge of the conceptual structure of chemistry can be employed to make learning more effective in those areas where the structure has been or can be explored) and, secondly, because a better knowledge of the conceptual structures of sciences may help in understanding the relations of the sciences among each other (not only between chemistry and physics as indicated here). If we succeed in conveying to our children and students a feeling for the relations between the sciences and between the world in which we live, we may be able to foster a new interest in them.

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Modified roles of the laboratory and other methods of teaching chemistry

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INTRODUCTION

Great progress has been made over the last two decades in the development of chemistry, resulting in the accumulation of new chemical facts and principles. Students should obviously learn more of the new discoveries in their chemistry courses but this calls for a detailed appraisal of the type of course to be offered and the teaching methods employed. Considering the large expansion of student intake at various levels of education, new methods of teaching chemistry should be initiated and their results precisely evaluated.

There has been a growing conviction in recent years that the standard lecture system of the traditional chemistry course is not very effective. This method of teaching has been subject to a number of criticisms, notably concerning the lack of two-way communications between the teacher and the student: the teacher presents facts and principles without allowing the students much time to ask questions.

It has been argued (1) that the traditional functions of a teacher, namely collecting, organizing and summarizing vast quantities of materials, stressing important points, repeating and reviewing facts and theories, and presenting interesting examples and illustrative materials, can be discharged by printed materials. It is further argued that, although the chief function of the lecture is to inspire students, some other way can be found to inspire them, such as supervising laboratory and tutorial work. It seems clear that in the traditional lecture system a direct feedback from the students in the form of questions, opinions, and criticism is not possible. The usual homework assignments and final examinations provide a delayed feedback which is not of the same value. On the basis of the above arguments, the traditional lecture system has been regarded as a waste of valuable learning time. The trend towards reducing the amount of time devoted to lecturing has become common in chemistry teaching at secondary and university levels.

During the last few years a major criticism of laboratory work in the teaching of chemistry has been the insufficient opportunity for student discussion in the performance of laboratory experiments, while the new curricula have put more emphasis on the role of inquiry. In an attempt to improve laboratory instruction, several schemes have been tried experimentally by various schools. In most of these schemes the 'cook book' procedures giving a detailed set of instructions have been replaced by more challenging experimental work in the spirit of independent research.

This paper tries to summarize the new trends in methods of teaching chemistry, including laboratory instruction, during the last decade. Emphasis will be on those experiments that attempt to develop the instructional procedures used to teach chemistry. No attempt will be made to discuss studies on the development of course description, or on the utilization of educational technology in teaching chemistry.

SYSTEMS OF INSTRUCTION

Various attempts and suggestions have been made in order to improve the instructional procedure of teaching chemistry courses. In such attempts, more emphasis has been put on the role of the students in the learning process. This is based on the assumption that the students can learn on their own whatever they are expected to learn in the traditional courses.Given this assumption, it seems that such a course can accommodate larger numbers of students than the traditional lecture course because the students are free to consult texts and other sources of information and perform laboratory investigations.

The Keller Plan or self-paced method

The Keller Plan, or personalized system of instruction (PSI), or self-paced study, was originally developed by F. S. Keller and J. G. Sherman some eight years ago. It was intended as an alternative method of teaching undergraduate courses. It is self-paced, mastery oriented, students' tutored instruction. (2) It is based on the concept that the student is an active element in the teaching process, rather than a receiver of information, while the teacher evaluates and responds to the student's effort.

It has been indicated that learning is a three-step process: presentation, response, and consequence.(3) This means that in designing an instructional system a sequence of these three-element cycles should be arranged in such a way that learning is optimized. The Keller Plan is regarded as an optimal means between the extremes of programmed instruction and a semester plan of lecture (presentation), final examination (response), and course grade (consequence).

In this scheme, the subject matter of the course is divided into units of work.(2, 4) A student works from a study guide which states what he should learn in each unit. Each study guide consists of a clear statement of the objectives of the unit, a reading assignment from one or more texts, optional readings, and a problem assignment.

When the student feels that he has satisfied the objectives of a unit he can ask the instructor for a test. The student writes the test in the classroom and presents it to his tutor who is an undergraduate student having already passed the course. When the student passes the test he is allowed to receive a study guide for the next unit from the instructor. However, if he fails he has to work further and take another test on the same unit.

The pace is left to the student. He can take as many tests as he wants every week, and there is no penalty as long as he finally learns the material and passes the test. What counts is progress, no matter how fast or slow, and failures on unit tests do not effect one's course grade.

The scheme provides lectures only sparingly and they are open only to students who are qualified to attend them: a student can only attend a lecture after he has passed a certain unit of work. The lecture is not to impart basic course materials, but is mainly intended to motivate students and to provide an example of a professional at work.

The laboratory programme accompanying the scheme is conducted in the usual manner, except that an open laboratory may be made available to enhance the self-paced approach that characterizes the scheme.

A student who successfully completes all the units is guaranteed a pass grade in the course, subject to satisfactory completion of the laboratory programme. He may raise his grade by showing outstanding performance in an optional final examination. Under certain conditions, a student is allowed longer than the usual period to finish his course.

The tutor plays an important role in the Keller Plan. He is expected to examine a student's problem assignment before giving him a test, in order to reduce the waste of the student's and the tutor's time due to inadequate preparation for the test. The tutor also detects problems and discusses errors after the unit tests.

The main role of the instructor is to provide study guides, to make tests, to administer and to review the testing programme, to supervise the tutor, to conduct the scheme, and also to help students with special problems.

A course manager may also be appointed.(5) His responsibilities are to assure that all the study guides and unit tests are available upon request during class hours. The manager also keeps records of the tests taken by each student. He is free to serve as a tutor, or may assume some of the responsibilities of the instructional staff, depending on his background.

The Keller Plan has been tried for the teaching of introductory chemistry courses. (6 to 8) In one of the programmes (7) the course material is divided into 19 units to be mastered in a given order. Two of these units contain only review material so that the students can learn to synthesize the topic as a whole.

A student who completes all the 19 units is guaranteed at least a B grade in the course, subject to satisfactory completion of the laboratory programme. Completion of 16 units is rated at C, and 12 units at D - the minimum passing grade. The laboratory work is graded on a pass/fail basis.

Eight lectures are offered during a semester and these cover more advanced or special interest topics; no effort is made to duplicate materials covered in the text.

It seems clear that the students respond enthusiastically to the system. Most of them feel that they have learned more under this system than they have using the lecture procedures. However, the end results of the scheme do not seem to be better than those obtained by the conventional method.

Modified individualized instruction

Several programmes have been developed to individualize chemistry teaching in the secondary school.(9, 10) They follow the structure and the characteristics of the Keller Plan.

In a particular programme,(9) the behavioural objectives of the course are arranged into a hierarchy reflecting the dependent and interdependent relationships between them. They are also divided into a set of basic objectives and optional objectives. Only a very few students can reasonably be expected to achieve the whole set of objectives within a school year. The practice of trying to achieve all the objectives in order, following the hierarchy, would indicate that some topics introduced early are studied too intensely while many other topics are considered by only a few students. Individualization of the programme is provided through optional objectives, and each student is permitted to learn at a pace geared to his own particular abilities.

Each student receives a complete set of the objectives in which the basic and the optional objectives are indicated separately. A copy of the hierarchy chart is also presented to the student in order to guide him in planning his study. Each student must achieve at least the basic set of objectives, and he is further encouraged to study areas of special interest to him.

The student is given a grade for the course whenever he has achieved all the objectives, or whenever he has demonstrated an acceptable level of performance for all of the objectives.

This experiment leads to the conclusion that the students learn more on their own than the conventionally taught students. However, very few students learn more than is necessary to meet the basic requirements of the course. In addition, only very few attempt to achieve objectives related to chapters beyond the next chapter to be examined. This means that the pace of most of them is determined by the examination schedule. It is therefore desirable to set an individual examination for each student whenever he is ready for it.

A similar programme has also been reported.(10) It is intended to provide students with an understanding of the relevance of a particular topic to the whole framework of the course. In this way it is expected that the students will see their goal and their progress continually, and be motivated to put in the effort and time to maintain and increase their progress.

In this scheme various topics to be covered during the chemistry course are classified under a few main headings. They are set out in a chart so that students can see the overall structure of the whole course, its goal, and the interrelationship between topics.

A student starts the course by selecting a topic to study. He then consults a set of file cards which direct him to various sources of information, such as texts, film loops, film strips, tapes, etc. The teacher gives help when it is needed. Whenever the student feels that he has learned and understood the information he can take a test by selecting a test card for his topic. There are also parallel laboratory sessions and essay writing or correlations which the student can select from a list of topics.

One formal lesson is offered each week to back up these approaches. However, attendance is not compulsory and materials covered revolve around those given in a hand-out. This sequence is repeated throughout the course after the student has determined his own routes within the chart.

In this programme the role of the teacher is to seek and prepare new teaching materials, and to work individually with students who may have special problems.

A programme to individualize chemistry teaching in an open secondary school has also been developed.(11) In this an attempt is made to individualize chemistry in a way that combines concepts and problem solving with laboratory experiments. With the aid of the teacher, each student establishes his own goals for the course.

In order to provide the necessary balance between concepts, problems, and laboratory experiments, the course is divided into two components: teacher-directed classes and student-directed laboratory sessions.

The teacher-directed classes are composed of 15-minute modules, up to three in number, and such sets of modules occurring up to five times each week, depending on the nature of the material to be covered. If the students need assistance in solving the problem related to the concept which has been introduced, problem days can be scheduled. Question days may also be scheduled to give the students an opportunity to ask any question related to the concepts, problems, or laboratory investigations. Student attendance at any of these classes is optional.

The concepts, problems, and question sessions are then utilized by the students in the implementation of laboratory work. The laboratory sessions are not scheduled, but the laboratory is open and available to students morning and afternoon. The student may come in and work whenever he has free time. Each student is provided with a large variety of open-ended laboratory investigations, the majority of which require that he take his problem into the laboratory in order to obtain a reasonable answer.

At the conclusion of each quarter the student and the teacher evaluate the progress made. This written evaluation becomes the student's permanent record. No grades are given and credit is not used or required for graduation.

The primary function of the teacher is to provide learning activities, from which the student can make his selection. These include a large variety of laboratory experiments, a varied cross section of chemistry problems, and a selection of concepts organized in such a way as to assure the structure of the discipline.

It is recognized that this programme is most suitable in situations where the majority of students will not need a profound knowledge of chemistry.

Minicourses or student self-selection approach

A student self-selection approach in science teaching at secondary level has also been developed in order to individualize education.(12) It is based primarily on the assumption that students learn most readily when they are given an opportunity to understand, discuss, and choose what they are to do and how they are to do it.

In this programme the course of study is divided into 17 units or topics. Resource boxes are assembled for each unit, containing charts, pamphlets, and supplementary readings pertaining to the theme.

Every six weeks, each student selects a new unit of study. Only six of the 17 units are made available every six weeks, in accordance with the number of teachers available. The new programme is explained to the students in a class meeting, which requires about 5 to 10 minutes every six weeks.

The course is centred around a guideline developed by the teacher, while textbooks are used only as references. Many other activities are also provided, such as laboratory experiments and group projects.

This programme has several advantages. The student is highly motivated because he can choose the course of study in which he is interested. In addition, each student makes a fresh start with a new course and perhaps a new instructor every few weeks.

Contract learning approach

Studies have also been carried out on programmes in which the student and the teacher jointly develop, through discussion and negotiation, a plan for a particular aspect of the course, and the resulting agreement or 'contract' is open to renegotiation as needed. (13, 14)

In one of these experiments (13) a student is asked to complete an independent research project, involving laboratory work and library research. The student, together with the teacher, determines how much work would be required to attain a particular grade level. While the quantitative aspect of the project is determined jointly, the qualitative aspect of the work is determined by the teacher. The student is asked to select a project to be investigated, and to indicate the grade he feels is realistic for him. The student is allowed to change this grade until a predetermined date. Together with the teacher, he also makes an agreement that if, at the end of the project, he achieves the standard of content and competence, he will receive the grade he had previously indicated. On the other hand, if he falls below these standards, he will receive a grade determined by the teacher. If the student does more work than he has previously been willing to do and has not asked for a change in his declared grade, he receives the grade he has originally indicated.

It has been suggested that students are aware that they are competing with themselves rather than with other students in the class. They like the programme because they know what is expected of them and what they can expect in return.

Tutorial and discussion approach

Tutorial and discussion approaches, in which the amount of lecture time has been reduced to a minimum, have also been studied experimentally.

In a tutorial approach,(15) the course of study is divided into several units. Each unit has detailed operational or behavioural objectives which spell out what the students are expected to learn, including homework assignment questions. A one-hour lecture plus several tutorial hours are provided each week. Students are allowed to attend additional tutorials if they feel these would be helpful.

At the end of each unit there is an examination whose results the students know the same day. This instant feedback allows students to prepare for a retest should they wish to do so. Students are allowed to take as many tests as necessary to obtain the grade they consider satisfactory. In an attempt to individualize instruction, students have a choice of several texts.

The laboratory is open for some 15 hours each week, and students can come in as often as they wish, but must attend the laboratory for a certain minimum time.

The evidence seems clear that this method of teaching is effective when the number of students is reduced to a minimum in order to allow the teacher to keep a close watch on their progress. It has also been claimed that this method has several specific advantages. It encourages the development of maturity and self-discipline among students, develops problem-solving skill by using open-book examinations, and encourages sound study habits by requiring homework assignments to be completed before each examination. Evidence has also been produced that this method leads to better achievement (and lower attrition) than is obtained by more conventional methods.

In a discussion approach,(16) a major portion of the teaching period is used for class discussion and tests.

The weekly teaching is divided into three periods. At the beginning each student is presented with lecture notes which highlight important parts of the material to be covered during the week. They also include problems and references to outside reading. After the student has studied the notes, a lecture is offered in which the teacher covers the highlights and answers questions. In the next class period verbal or written questions are discussed.

The last period is used for an examination, covering material outlined by the notes. The last portion of this period is used to discuss the examination, and new notes are handed out.

This sequence of periods is repeated two or three times. Afterwards an examination is given covering all the materials outlined by the previous two or four notes.

It seems that this method is liked by the students because they have good lecture notes, and are free from the frantic writing which they have to do in traditional methods of teaching.

Small group approach

Another version of chemistry teaching with a minimum amount of lectures has been undertaken.(17) With the elimination of lectures, formal teaching is concentrated on laboratory work and tutorial assistance. For this purpose, the students are divided in each course into small groups of about 10, and a tutor is assigned to each group.

Each student is provided with a guide, enlarged upon by a suitable text. A regular assignment is set to establish contact between student and teacher. When the student has completed the assignments they are marked by the teacher with appropriate comments, then returned to him. In this way the student recognizes his progress, while the teacher can assess the performance.

Maximum integration between tutorial and laboratory work is one of the outstanding characteristics of this scheme. Each small group is provided with a specially designed laboratory bench and sufficient space for discussion and tutorial sessions.

The structure of this programme has also been applied to external correspondence courses in chemistry. The external student is expected to attend on-campus school for a certain period each semester, during which laboratory work and discussion are conducted. The discussion is recorded, and a copy of the tapes is sent to the student in order to assist him in recalling the whole atmosphere of the laboratory discussion. The occasional lecture given on campus is treated in a similar way.

It has been concluded that the small group teaching method has several advantages. Homogeneous groups can be formed, based on the ability of the student. This makes it possible to treat each of the groups differently with respect to the method of teaching and the amount and depth of the subject matter presented. In addition, emphasis can be placed on the development of an ability to communicate ideas, and on the improvement of the student's self-confidence. This aspect of the course also allows a continuous evaluation of each student without too much reliance on a formal written examination.

The British Open University course

In an attempt to provide a university education for workers in the United Kingdom, an Open University course has been developed.(18, 19) It is currently in its second year of operation and has aroused considerable interest. There is no campus, and there are no entrance qualifications, although students have to be at least 21 years old.

The science studies of this programme consist of an integrated course composed of 34 conceptual units, covering chemistry, physics, life sciences, and earth sciences. It takes 44 weeks to complete, involving the students in about 10 to 15 hours of study each week. The total enrolment for the course is approximately 10,000.

The course is designed so that the student can learn at home. The study materials, such as texts, study guides, assignments, and experiments are transmitted by mail, television and radio. The experimental part of the programme is based on a home kit supplied to students.

Tutorial sessions are available at regional centres. Students are also expected to attend a summer-school week comprising intensive laboratory and tutorial work.

A student's progress in the course is evaluated in five ways: self-assignment, computer marking, tutor marking, summer school marking, and a final examination. All, except the first, contribute toward the final grade.

It has been found that the original idea, to provide a post-school education for British workers, has not been successful since the working-class enrolment is very small. This indicates that education cannot be imposed on people who do not genuinely desire it.

LABORATORY INSTRUCTION

The need for improved laboratory instruction in chemistry has long been recognized. Many arguments have been put forward to explain the need, such as the following. (a) In the traditional chemistry course, consisting of 1 or 2 hours of lectures plus 3 or 4 hours of laboratory work each week, the presentation of chemistry as an experimental science is very difficult. The chemical facts and principles are very often first presented in the lecture and then exemplified in the laboratory. As a result, students have no opportunity to act as scientists or learn how scientists work. (b) Another weakness of the traditional laboratory programme is that students are given a course-connected series of experiments which show little relationship between experiments in one course and another. Such a programme is not sufficient to meet the needs of students' diverse future careers. (c) After students have completed their laboratory course organized in the traditional manner, they are not capable of performing the very basic techniques when placed in a new situation, in other words, they have not learned how to use an experiment to solve a chemical problem.

The answer to the present furore over the validity of the traditional method of laboratory instruction seems to lie in a clear definition of the role and nature of experimental work and the practical means of achieving them, in some kind of measurable way. It has been submitted that practical work in chemistry may be divided into several types:(20)

1. Experiments done by students.
2. Experiments shown directly to students.
3. Experiments shown indirectly to students by the use of some kind of visual aid.
4. Experiments which are merely described, either verbally or in writing, by the teacher or in a book.

It is assumed that the order of priority at school level is 1>2>3>4, and that only the classical experiments come into category 4. At the tertiary level, categories 1 and 4 are predominant.

It seems also clear that, in order for experimental work in chemistry to be productive, it should include several currently accepted objectives of laboratory instruction. Some of the objectives are:(21)

1. To develop observational, manipulative, preparative and instrumental skills.
2. To acquire, illustrate and amplify chemical knowledge.
3. To stimulate thought through experimental interpretation.
4. To recognize the precision and limitation of laboratory work.
5. To record accurately and communicate results clearly.
6. To develop personal responsibility and reliability in conducting experiments.
7. To plan and carry out further laboratory work by the effective us of available laboratory resources.

Specific behavioural objectives implicit in each of the above objectives should be recognized and understood by the students, and their degree of achievement evaluated by the instructor. There is no doubt that the actual marking of practical work is a difficult matter. However, in order to avoid conflict between the objectives of laboratory work and its assessment, the instructor should make a thorough analysis of what is meant by practical work.

The amount of laboratory work in chemistry courses has also been seriously questioned. It has been reported (21) that the total number of hours being spent on laboratory work during a three-year undergraduate course in the United Kingdom amounts to about 1,000, while the figure is over 2,500 hours for a course lasting 5 or 6 years, in some European countries. However, the pressure exercised on the school chemistry curriculum by the examination syllabus,with the heavy demands it implies in terms of amount of material to be covered, tends to minimize the time which can be spent on practical work. Several schemes, such as the Nuffield scheme in England, have tried to remedy this situation by ensuring that the chemistry curriculum depends on practical work, rather than practical work being no more than an optional extra. In the Nuffield scheme the emphasis on practical work is reflected by the fact that practical marks represent about 12 per cent of the final overall marks.

Pessimism about laboratory work as a suitable educational device has given way during the last few years to a great interest in the improvement and development of laboratory instruction in chemistry courses.

Discovery method or problem-solving approach

Although the amount of time spent in the laboratory varies between schools, there is an increasing awareness that chemistry should also be taught in the laboratory in order to emphasize the character of the discipline as an experimental science.(22) Laboratory experiments should be made the centre of interest right from the beginning of a study of chemistry. It is interesting to note that in a study of the inquiry-discovery method of laboratory instruction (23) it seemed clear that, in a variety of actual learning conditions, the inquiry method of learning results in significantly better performance by the students compared with the conventional laboratory procedures. It has also been reported (24) that students' performance in the chemistry laboratory can be enhanced by student-centred procedures. In such a programme the students have more freedom to discover and clarify the learning goals, and can develop the habit of thinking through a problem on their own initiative.

An approach to laboratory instruction for freshmen has been developed (25) in order to achieve the above objectives. In this approach the traditional courses of one hour for lectures and four hours for laboratory work each week is replaced by two four-hour periods each week. During these the students work both in the classroom and in the laboratory. The scheme gives each student an opportunity to discover for himself much of what is ordinarily given in the lecture. The student is also confronted with problems and is expected to devise an explanation based on his experimental results.

It has been found that this approach is a very good tool to introduce and illustrate topics that might be found abstract in a lecture but which become real in the laboratory. Another important aspect of the approach is that the students gain a deeper understanding of the methods of science, by being required to interpret and analyse their experimental results.

Another scheme, a problem-solving approach, has been tried experimentally. In this approach the students are given analytical or preparative assignments.(26 to 28)

The programme consists of the determination of physical properties and their measurements, various methods of analysis, identification of unknowns, and syntheses of compounds. The task of the students is to collect data by using any means available and to interpret these data. Prior to each laboratory session a lecture is provided for the discussion of various manipulations and laboratory techniques, and of chemical literature searches. After a student is given an assignment, he has to write up in detail an acceptable procedure which could be carried out with chemicals held in the laboratory. The laboratory is open the whole day.

The findings of this study indicate that students' response to the scheme is very favourable, because they can see practical reasons for doing laboratory work. The scheme teaches students to decide which procedure or test is to be applied in order to provide the necessary information, and to make deductions on the basis of their results. However, implementation of this unstructured approach to laboratory instruction seems rather difficult at school and in the early years of undergraduate courses, because of the extensive resources it requires. The approach also makes large demands on faculty members, and the programme can only be effective for a large student enrolment with highly dedicated and competent teaching assistants.

Integrated laboratory instruction

An integrated approach to laboratory instruction covering several semesters has also gained some ground during the past few years.(29 to 31) This approach is intended to help students realize that chemistry is a single discipline, in which organic, inorganic, etc., are interrelated and interlocking parts. Lecture and laboratory courses are separated just as if they were two different courses. However, the laboratory course is designed in such a way that it blends the various sub-disciplines in individual courses.

The programme consists of several laboratory courses following the freshman year. In order to assist students to carry out their laboratory work, each laboratory session begins with a discussion on techniques, and an elaboration of the principles involved in the experiment.

In one such programme,(30) the experiments are organized by levels of sophistication. Types of experiment include various major topics in chemistry. The programme is designed so that laboratory experiments correspond to the contemporary activities of practising chemists. This is achieved by selecting experiments based on results reported in the current chemical literature. At the beginning the students are not completely free to choose their experiments and must take certain basic experiments, but beyond them they can choose any of the experiments on a list.

Research problems are also an integral part of the scheme, and in these experiments students may participate in an ongoing research project conducted by a faculty member.

Lectures may also be provided as a part of the laboratory course. They are more sophisticated and more theoretical than the usual simple instruction in conducting an experiment.

It has been claimed that enthusiasm is generated among the students and staff because of the individuality of each programme. Each student's programme is tailored specifically by himself. Also, the research nature of the high-level experiments imparts a degree of realism. Another important feature is the high level of personal contact between faculty members and students. However, this programme presents an organizational problem. It also demands a great deal of faculty time, resulting in less time available for class preparation and research.

Winter term or interim course

The value of research experience for undergraduate students has been widely accepted in recent years. However, it has been felt that students have only a limited amount of training in how to conduct laboratory experiments at a high level, following undergraduate courses. This is possibly due to the limited amount of equipment available. There is no doubt that the teaching of a variety of experimental techniques not only improves the laboratory proficiency of the students but also enriches those mental processes which control the type of research done. Thus, it has been suggested (32) that an advanced laboratory course for senior students is desirable, developed around the interests of faculty members and involving close personal supervision by reasonably proficient persons. The course can be offered during a short period of four to six weeks between semesters in order to give students the opportunity of working for an extended period in the laboratory. The availability of such an extended period of time each day and freedom for both instructors and students from the demands of other courses are particularly significant, providing richer, more penetrating, and more varied experiences in the laboratory.

A great variety of programmes and opportunities have been introduced during the past few years following the winter term concept. (33 to 36) This course involves a small number of students, for a period of one month, in the study of a single subject in as much detail as time allows. Projects offered in this course may be related to the ongoing research interests of the faculty, or be specially designed in order to instruct students in particular techniques or investigative skills, or may take the form of less technical projects designed to furnish a meaningful science experience for non-science students. The course usually has a prerequisite of two years of undergraduate study. Several faculty members share equally the responsibility for the course lectures and laboratories.

In one of the programmes (34) the course is divided into three periods, and each period emphasizes a different aspect or level of involvement in theory and laboratory practice. The programme begins with a discussion between the students and the faculty members. This discussion leads to a selection of a specific problem. The students are then directed to the literature and are asked to prepare a working plan. Additional discussion between the students and the faculty members will result in a final working plan for the programme. The programme can also begin with class instruction after which a student is introduced to the reference and journal literature. During this period, he receives instruction on how to keep a research notebook, and demonstrations on the uses of individual pieces of equipment are also conducted.

During the second period the student is given a library assignment, e.g. a detailed laboratory procedure for the synthesis of a specific compound. It is followed by a laboratory assignment consisting of identification of unknowns on the basis of chemical and physical analyses and the synthesis of a compound. Frequent discussions between the student and the faculty member result in a clear direction of the work.

There is no written examination and students are evaluated on the basis of their overall performance.

It has been claimed that when a student has completed the assignments given in the programme, he has been exposed directly to many of the distinctive features of chemical research. The students respond with interest and enthusiasm to the course, and the faculty involved found that the course is very stimulating to teach. Another advantage of the winter term course is the flexibility afforded an instructor in designing his course. Because each student is confronted with his own problem, considerable individual iniative is also developed.

A very similar programme has also been undertaken (37) in which the students are placed in the environment of a large research laboratory away from their usual academic surroundings. In this programme the student receives academic credit from his participation in research and seminars organized by several faculty members in residence at the laboratory. Students selected for this programme are expected to have both a reasonable background in chemistry and motivation.

In this programme students take several courses which require a certain amount of problem-solving. The research component of the programme may occupy some 50 per cent of the student's time. Each student is also required to write a report on his research. The type of work he does varies from a completely independent project to that involved in team research.

One aspect of this programme is that it permits students to become familiar with areas they can not be instructed in on the campus. It is also beneficial to the students for gaining insight into research processes in a very sophisticated environment, which should help them in their careers as scientists.

CONCLUSIONS

Considerable efforts have gone into the development of improved instructional procedures in chemistry teaching during the past decade. Many of the experiments in this field have been concerned with individualized instruction providing maximum freedom and flexibility both for the students and the instructor. This approach has been based on the premise that students are individuals with different abilities, backgrounds, interests and motivations. In this approach the amount of lecture time has been reduced to a minimum, being replaced by discussion, tutorial- and assignment methods of instruction. However, the majority of the individualized chemistry programmes developed during the last few years tend more toward curricular variety, and lack related laboratory experiments. This is possibly because individualization of chemistry is not an easy task. There is a need to balance concepts, problems, and laboratory experiments in such a way that the structure of the subject is preserved. In general it has been found that individualized instruction is better than the traditional procedure in terms of the development of students' attitudes and motivations. However, there are no definite results to indicate that the overall gains are better than those obtained by the conventional methods of instruction.

It also appears that the demands of the normal school curriculum and pressure of external examinations will not allow full development of, or much emphasis upon, individualized instruction. Other constraints on the implementation of the scheme should also be recognized, such as individual differences in students' independence and learning style, and inadequate resources in teaching materials and personnel particularly in most of the developing countries. In addition, individualized instruction demands particular attitudes and a lot of the time of the instructors. It may be concluded that further experimentation in the individual method of instruction is necessary, particularly for large classes. Wherever possible, such instruction should be conducted parallel with the traditional method.

There are also trends towards modules and minicourses programmes which offer further alternatives for the student, thus resulting in increased motivation. However, the resultant gains obtained by these procedures are not yet clear.

The United Kingdom Open University concept has also gained some ground.

In several experiments a definite attempt has been made to improve the role of the laboratory in chemistry courses. It is clear that chemistry programmes have placed more emphasis on laboratory work. Longer periods have in general been devoted to laboratory instruction. However, the emphasis has been more on the method of seeking answers in the laboratory than on learning the exact techniques of the discipline.

The integrated approach to laboratory instruction has found more practitioners during the last few years. Their studies point to the conclusion that it generates enthusiasm and critical thinking among the students. However, the high level of sophistication practised imposes too heavy a burden on resources.

The winter term programme has been practised by many schools. It seems a very suitable scheme to enhance the student's competence in laboratory techniques or investigative skill and to develop scientific attitudes.

In general it may be concluded that the various methods of teaching chemistry reported in recent years have made a useful contribution to the rapid expansion of chemical education. They are in the process of development, awaiting further experiments in the coming years. The overall gains of each of these procedures need further study before one can decide which procedure is suitable for any given condition. The traditional lecture may still have its merits, but the emphasis in teaching should develop away from traditional ideas. Lectures should be of high quality to allow an exchange of information between the lecturer and the students. It may also be concluded that there is a trend towards more time being spent in the laboratory during chemistry courses. However, laboratory assignments should include specific behavioural objectives implicit in a statement of laboratory purpose, recognized by the student as the criteria upon which his performance is evaluated.

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The enhanced potentialities of new educational technology

by C.N.R. Rao

INTRODUCTION

Modern audio-visual and electronic teaching aids (1, 2) have added a new dimension to science education. Today, educational technology is effectively employed as a means of enhancing the quality of education. Typically, educational technology is defined to include educational television and other audio-visual media, programmed instruction and computer-assisted instruction. In the last few years, experiments employing these tools of educational technology have been carried out extensively in various centres around the world. These studies have resulted in an encouraging situation where the tools of educational technology supplement and support the efforts of teachers and students in the educational process and become part of the learning experience itself.

We can consider the media of educational technology as delivery systems for the subject matter. They offer the advantages of the printed page and in addition possess other important and valuable features. In principle, audio-cassettes, video-cassettes, and computer terminals can be used, like books, for study at any time the student chooses. The important difference between the book and the other media, however, is the variety of human stimuli that each engages to provide parallel paths to the brain. While the printed page uses only the eye, the audio system can use both the eye and the ear. Films or TV programmes add the dimension of motion. These new technologies also share the weakness of the printed page - the lack of direct, active interaction with another human being, the teacher. The computer, used properly, can provide some opportunities for interactive learning. The various media of educational technology can be used for instruction not only in the regular schools and universities, but also in programmes designed for continuing education and correspondence courses.

It is important to realize that media of educational technology do not merely involve hardware, but the overall design of the whole range of learning situations.(3) In designing learning situations, there should be a clear understanding of the objectives of the learning area, the requirements of the learner, the final objectives of the programme, the nature of the personnel, the hardware and other material requirements and the organizational structure. Within such a framework, one should see where the media fit in. Teachers need to evaluate critically the use of any particular medium, both in terms of its effectiveness and cost. Educational technology, handled properly, can answer the crying need for improved techniques in science education at all levels and provide individualized as well as self-instruction to students, while still coping with the large flow of students entering higher education. In this paper, we shall briefly review the increased potentialities of educational technology in chemical education based on the recent literature on the subject.

PROJECTORS, SLIDES, FILMS, AND AUDIO-TAPES

The projection of slides, transparencies and film strips (2, 4, 5) has been used for some time in classrooms for purposes of illustration, particularly while discussing complex structures, models, mechanisms, graphical presentation and so on. Today, projection facilities of varying degrees of sophistication (2) are an integral part of lecture halls, carrels and auditoriums. To understand spatial relationships in structural chemistry, stereoscopic viewing (6) is particularly effective. A simple slide projector can be modified into a time-lapse multiple slide projector,(7) where by simply pushing a button the first image begins to dim and disappear while simultaneously the image from the second slide is projected. This arrangement is good for showing molecular rearrangements, intermolecular interactions, etc.

Material stored in the form of micro-images (microforms) is handy in teaching.(8) On such microforms, data, problems, laboratory instructions, spectra and other information can be stored with the highest possible storage density. Microform cards can be used with electronic data processing machines; they also provide compact individual libraries.

Overhead projectors have been widely used by teachers in recent years.(4, 9) Some important applications consist of the projection of transparencies and slides for lecture demonstrations and simulation of certain phenomena. (4) The well-known series of lecture demonstrations described by Alyea employing the TOPS projector and Plexiglass cells have been documented extensively in the Journal of Chemical Education. Overhead projector experiments in electrochemistry,(13) colloid chemistry,(14) and several other areas have been described by various authors.

Use of 8mm projectors to show film strips has become extremely popular. Of the 8mm film formats, the super-8mm has proved the most useful.(5, 15) Barnard (5, 15) has reviewed the relative merits of the different 8mm formats and equipment. Super-8mm films are readily used in classrooms during lectures or in help sessions. Single-concept film strips are inexpensive and extremely useful in providing ready and vivid explanations.

The availability of relatively inexpensive cassette tape recorders (16) has been a boon to chemical education. In addition to recording classroom lectures, cassette tape recorders have been employed to provide laboratory instruction (17, 19) and explanations of experimental calculations,(20) to clear up students' doubts,(18, 21) in tutorials (22) and so on. Use of audio-tapes minimizes scheduling problems and undoubtedly provides a useful supplement to traditional instruction. In one centre, each student in a physical chemistry course has been provided with a cassette tape recorder to enable him to record lectures and to obtain individual instruction from the teacher.(21)

A combination of cassette recorders and cartridge film loops (with sound track) has been effectively used to teach laboratory courses e.g. on chemical separations and instrumental analysis.(17) In some experiments where the tape alone cannot provide the information clearly, the film gives a visual demonstration of laboratory techniques. Although the initial cost is high and considerable time is consumed in setting up initial experiments, this method of teaching has elicited great student interest and has enabled better laboratory instruction to be provided; students are able to work at their own pace and can have more fruitful discussion with teachers in laboratory sessions. A combination of audio-tapes and slides is found to be effective in the discussion of laboratory experiments and lecture topics;(23) the performance of students using these facilities has proved good. Whenever audio-taped instruction is given, it is generally necessary to hand out specially prepared written material to students.(20, 23)

The use of 16mm movies to illustrate concepts or to explain phenomena has been in vogue for a long time. Films shown during lecture hours or help sessions have elicited good response from students. While the advent of television has taken away the unique importance of 16mm films, they continue to play an important role in chemical education. Films are easily transported and stored and can be used with TV or for direct projection. However, in many parts of the world, teachers find it difficult to obtain educational films and it is most important that international efforts be made to ensure that films are readily available. It should not be necessary to duplicate efforts by making films in every country; if important concept films in English or any other language can be freely dubbed into other languages (or used with sub-titles), this would already be a great help. Gloriosov (24a) and Gomel (24b) have reviewed the utilization of films in chemistry teaching. Tressel and Barnard (25) have discussed the importance of the technique of animation in chemistry films and also some aspects of editing.

Films in chemistry can be broadly classified into two categories: (a) concept or theme films which attempt to clearly bring out a phenomenon or a concept, and (b) curriculum movies which cover a specific area in some detail. A package of films of the latter variety covering an entire course or a curriculum (e.g. a package of 15 to 20 films on general chemistry) would be beneficial to students, teachers and institutions, particularly in situations where facilities and opportunities are minimal. If such films are made by good teachers and are supplemented by proper instructional material, satisfactory chemistry classrooms can be set up in all corners of the world. Films on topics of general interest, such as molecular vibrations and spectroscopy, crystal structure, and symmetry, have been very popular and will undoubtedly be made in larger numbers in the future. Topical films made by leading figures in chemistry continue to be received with admiration by students and teachers.

TELEVISION

Television is probably the most powerful audio-visual educational medium. It has provided new dimensions and opportunities for instruction which were previously non-existent.(26) Through television, instructors can show things to students which would be inaccessible in traditional instruction. Students can participate in live laboratory experience and training which would normally be impossible to provide to large classes. Television and video-tapes have been used in classroom demonstrations to show close-ups of experiments. Television broadcasting is employed to reach students located far away from the teaching institution. Use of mobile facilities enables the instructor to take the class on location to a laboratory or industry. Television is generally less expensive than film production.

In spite of the many advantages of television, it remains the most controversial of all the media.(26) Some teachers consider the effort in television to be too time-consuming and feel that it threatens the autonomy of the individual teacher and his 'privacy' in his teaching relationship with students. Except in the simplest of applications (viz., single camera demonstration in a laboratory or a classroom) television usually involves 'outsiders' and 'advisers' and many teachers are sensitive to this aspect. It is often difficult for teachers to find common ground with the advisers and production experts as regards the objectives or methodology of production.

Many teachers are sceptical as to whether video recording contributes significantly to instruction and are not sure that the self-appraisal resulting from watching one's own performance on television is necessarily healthy. Years of evaluation have shown that televized instruction and conventional methods of instruction are equally effective, and it is therefore sometimes asked why television is needed at all. While most teachers would welcome an opportunity to present their classes with occasional televized lectures by great teachers, they would not like televized lectures or programmes to interfere with the organization of their courses. Trotter (26) has discussed the controversy and applications of television at some length.

Most teachers believe that television does improve student observation in lectures (through demonstrations) as well as laboratory sessions and reduces faculty time devoted to the teaching of laboratory techniques.(27) In fact, television is very effective in providing uniformly sound laboratory instruction and closed circuit TV has been used extensively in many institutions for this purpose.(28) Even with closed circuit TV, there should be guidance from demonstrators and teaching assistants in the laboratory. Television has also been employed in problem sessions using two-way audio and video communication. In all such instances, it is desirable to provide students with specially prepared material on the topic concerned.

Barnard et al.,(27) have discussed at length television applications in chemical education. In another article, Barnard(29) reviews the hardware required in a good TV system. TV projection equipment capable of showing 14 ft images is found very useful in lecture demonstrations.(2) Instant TV replay is useful in lecture demonstrations of e.g. the phenomenon of supersaturation.(30) Colour broadcast TV has been tried out in some centres with success. Barnard (2, 27) has emphasized the need for properly designed classrooms and laboratories suitable for TV instruction.

Although TV broadcast lectures may not always be as effective as regular classroom lectures, we should not undervalue broadcast lectures to students located at a distance from the University. The Open University experiment (26) has shown that TV broadcasts are fairly well received. In the past, airborne TV has been used for instruction in the U.S.A., but has not obtained much support in recent years.

By far the most effective use of television has been in laboratory instruction.(27, 32 to 35) Taped programmes have replaced regular discussion classes in some centres;(32) such programmes attempt to answer the various questions students may wish to put. In addition to the first-year college chemistry laboratory instruction,(28) courses on instrumentation (34) have been taught on television. Laboratory techniques, actual operation of instruments, sample handling techniques, are ideally shown on TV; mobile TV is especially suitable for showing on-the-spot situations.(34, 35)

In the near future, video-cassettes are likely to become popular in some of the advanced countries. With these, the student can run the programme back and forth for self-instruction. Video-cassettes will probably be most useful for lecture and laboratory demonstrations and for tutorials.

Today, many chemistry teachers produce video-tapes for laboratory instruction or tutorial classes without much investment in time or paraphernalia. It is standard practice in many centres to prepare new programmes for laboratory sessions every year. However, care should be taken to ascertain that TV is in fact the best medium for the particular topic or experiment. Otherwise, over-enthusiastic use of TV may itself make instruction routine and unexciting to the student. While television may minimize schedule conflicts for students (33) and optimize the use of faculty time,(35) it could make education much too impersonal, unless teachers are on their guard. Smirnov and Drizhun (36) have discussed the basic criteria for the selection of educational material and for setting up television transmission of chemistry lessons.

OPEN UNIVERSITY

The Open University in the United Kingdom is developing a unique system of teaching and learning at the university level. The university is designed to provide part-time opportunities for a large body of adults who would otherwise be unable to enrol in conventional universities. The system includes specially written texts, television and radio programmes, experiments performed at home with home kits, continuous assessment by means of computer-aided objective tests and so on. In the foundation course in science (which includes chemistry) television and radio programmes form an important part of the instruction.(26, 37) Based on the feedback from students, these programmes are continually improved. The science course uses television to provide a substitute for normal laboratory experience. This aspect is considered so important that students unable to see these programmes on TV or in the films at the study centres are not encouraged to enrol for the course. The success story of the Open University demonstrates the value of long-range television and radio broadcasting in instruction, particularly as these programmes seem to have passed the test of public scrutiny.

PROGRAMMED LEARNING

Programmed instruction provides information required by the students in the order most helpful to them and enables students to put two or more ideas or facts together to derive a unifying principle or to explain a difficult concept. Good programming does not emphasize 'drill material'; poor programming overemphasizes the 'stimulus-reward technique' and provides little opportunity to students for self-instruction and initiative. Evaluation is part of any good programmed instruction. Both linear programmes (involving a series of expository statements where students are subtly interrogated) and intrinsic programmes (involving a series of pairs of exposition-question sets) have been employed by teachers all over the world.

Programmed learning has been found to be a very satisfactory method for teaching certain aspects of chemistry such as stoichiometry, structure, thermodynamics and kinetics, and a variety of programmes have been worked out. Programmed instruction in chemistry was the subject of a symposium in 1963 and the articles related to the symposium have been published in the Journal of Chemical Education (January 1963). Programmed lectures on high school and college chemistry,(38) programmed laboratories (39) and examinations (40) have been described in the recent literature. Young (41) has reviewed the literature on programmed learning up to 1966. Hogg and Moyes (42) have reviewed the British experiments in programmed learning. Several authors in other countries have also discussed programmed instruction. (43 to 47) A bibliography on programmed materials has been published recently,(48) and undoubtedly there are many unpublished programmes available around the world. Programmed instruction will undoubtedly be used by more teachers and institutions in the years to come. The Association for Programmed Learning and Educational Technology in London publishes a journal, Programmed Learning and Educational Technology. The proceedings of the annual conference of the Association, Aspects of Education Technology, include much information on programmed learning. Although a large proportion of material on programmed instruction is available in the published literature, there is bound to be a fair amount of unpublished material in various schools and colleges. Efforts should be made to see that such material becomes available to all chemical educators. Of the many media of educational technology, programmed instruction, a technique first used by Socrates, is relatively inexpensive and can be readily and effectively used in most institutions by most teachers.

COMPUTERS AND COMPUTER-AIDED INSTRUCTION

The role of computers as an important, active element in the instructional process has been investigated for more than a decade. Computers have been used in recent years in primary education, in university classrooms and in vocational training to accomplish a variety of purposes ranging from limited assistance within and without the classroom to total replacement of the teacher. There seems to be general agreement that computers facilitate individualized instruction and flexibility in instructional strategy. Cost and institutional resistance are often mentioned as common hindrances to the use of computers in instruction.

The beginnings of machine teaching can be traced to the pioneering work of Pressey in

1926 and to Skinner's refinement (49) of programmed learning during the 1950s. Today, various centres are carrying out a large number of projects of all dimensions and levels on computer based instruction. The three factors which have contributed to the growth of computer based instruction are (a) its tremendous potential for meeting most educational needs, (b) its learner-centred nature, and (c) the mushrooming of the electronic data processing and time-sharing systems. Teaching by computer is known by many names: computer assisted instruction (CAI), computer managed instruction (CMI), computer based instruction (CBI), computer assisted learning (CAL) and so on. CAI is the most commonly used name and rightly gives the idea that the computer is used to aid both students and teachers in the educational process. There is a two-way communication between the man and the machine where the main objective is human learning and retention. CAI is not synonymous with programmed instruction as some may consider. Today, the computer is programmed to provide individualized responses to differing student enquiries by employing algorithms. CAI does not require the programmer to anticipate all conceivable student responses so as to compare with the correct answers stored in the machine. Programmed instruction is unable to cope with teaching strategies which do not call for specified student responses.

Computers are most commonly used by chemical educators to simulate physical or chemical systems, as problem-solving aids, to analyse experimental data or to familiarize students with programming, on-line computing and digitization of data and the like. Some centres have a large number of computer terminals located near classrooms, laboratories, library carrels and dormitories. Tabutt (50) has reviewed computer applications in chemical education, while Feldhusen and Szabo and others (50) have reviewed developments in computer assisted instruction.

Several teachers around the world have been training undergraduate students to use computers to solve chemical problems. Courses are taught in numerical methods in chemistry, (51) on-line computer applications in analytical chemistry and instrumentation,(52, 53) chromatography (54) and other subjects. On-line applications in gas chromatography,(53) kinetics,(55) and other areas have been described. With the recent developments in electronics, it is now viable to collect data for many chemical experiments in digital form; not only are digital data very accurate, but they are also readily processed by computers. (56) It is, therefore, important that students become familiar with digitization of data during their undergraduate or post-graduate training.

Interactive on-line computing provides the student with a capability which enables him to carry out sophisticated mathematical operations.(57) With a single keyboard-display console, students can handle problems involving mathematical models and simulate experiments. (57, 58) Simulation provides rich experience in the analysis and presentation of data and in making hypotheses. Students readily work out orbital contours, rotation spectra, theoretical NMR spectra, probability diagrams, etc., using the computer.(57 to 59) Even without a detailed knowledge of the mathematics involved, 'qualitative' computing involving graphical display of some aspects of chemistry such as orbital contours is still very useful.(60) Laboratory-equivalent computer experiments such as acid-base titrations or gas laws are performed in some centres.(58) Computer based simulation of laboratory problems in qualitative chemical analysis has been reported.(61)

Computer animation provides a new insight into the study of molecular vibrations, intermolecular interactions and other complicated processes.(62) Computer animation of reaction pathways (like the film of Clementi on the $NH_3 + HCl \longrightarrow NH_4Cl$ reaction), provides an understanding of how reactions occur.

Although computers have become the fashion of the day, much can be accomplished by using inexpensive programmable calculators. With these calculators, students can carry out experiments (e.g. titrations, rates) and solve problems of a fair degree of sophistication. (63, 64) Programmable calculators can be easily located in most laboratories and can be widely used by a large body of students. This may be the best alternative to a readily accessible small computer in the teaching laboratory.(65)

Computer assisted instruction (CAI) has been attempted in many centres with varying degrees of success.(18, 66 to 73) CAI allows individualization of instruction under the control of a teacher. It takes advantage of the rapid retrieval capabilities of time-sharing computers operating in a conversational mode and employs specially constructed languages (such as APL, PICLS, Course Writer Series and PLATO) to develop programmes that can conduct a rich dialogue with a student. The logic of the dialogue is contained within the control words in the language. The terminals on which the students obtain CAI can be located anywhere. CAI has been used to manipulate experimental data, simulate experiments and to provide remedial or drill programmes at various levels of undergraduate chemical education.(66-73)

Computer assisted instruction in the physical chemistry laboratory has been found quite satisfactory and somewhat superior to conventional or programmed instruction.(71) Employing the PLATO system, chemical reaction stoichiometry has been taught to beginning chemistry students.(67) Instrumental analysis and radiochemistry have been taught through CAI. (72, 73) CAI in organic chemistry has been quite successful;(68 to 70) organic reactions, qualitative analysis and organic synthesis have been incorporated in such programmes. In CAI in organic chemistry, the decisions and the actions of the students controlled the progress and the students were directly involved participants.

In spite of the variety of experiments in CAI, the revolution in the classroom predicted by its staunch proponents has yet to take place.(74) There is still considerable scepticism among teachers as to the future role of computers in education. Industrial firms with competence in CAI seem to be adopting a wait-and-see attitude before developing their products any further.(74) While discussing computers in education, Young (75) has expressed the fear that computer aided instruction may become mere programmed instruction, unless considerable care is exercised. Young suggests the following guidelines to be kept in mind while employing CAI: (a) built-in provision for teacher-student interaction; (b) opportunity for the student to exercise his own initiative and possible computer recognition of the iniative; (c) possibility of slightly different responses for the same input.

OTHER POSSIBILITIES

Interdisciplinary areas. Use of educational technology in teaching of interdisciplinary areas with a significant chemistry component should be studied in detail. It is important that young students be exposed to the frontiers of emerging disciplines through the media of educational technology. It is possible that audio-visual media may make a greater impact on students in the interdisciplinary areas than in the traditional disciplines. Since chemistry has interfaces with physics, biology, environmental science and a variety of other areas, it is important to bring out through educational technology how chemistry has indeed developed into chemical science. Such an effort would also enable us to popularize chemistry.

Continuing education and correspondence courses. Teachers who practise their profession in schools and universities, are not always sensitive to the educational needs of a large section of the population which is not enrolled in any school or university. This population, which exceeds the combined strength of the students in schools and colleges, consists of people who have completed their formal schooling and are now employed as chemistry teachers or as chemists in industry, government establishments, or elsewhere. These chemists must combat technical obsolescence throughout their professional careers by means of continuing education. Their need is great, but the conventional educational system does not serve this need adequately. A large proportion of chemists does not live in the vicinity of a university, and even those who do, are not able to attend courses at fixed hours. A few universities offer evening classes convenient for continuing education, but these serve only a small number of chemists.

It is here that the new educational technologies offer tremendous potential, because they eliminate these constraints of time and distance. One major difficulty, however, is the almost prohibitive cost, particularly when the student body consists of widely scattered individuals, and when the major needs of the student body are in relatively esoteric topics which do not provide the large population base essential for the practical support of some of the media of educational technology, particularly the interactive computer programmes.

Correspondence courses can provide contact with another human mind. While the contact is not direct in the face-to-face sense, it can be quite real and productive. Its advantages are that it is inexpensive, and that it can readily be used for esoteric subjects in which only a small number of people scattered far apart may be interested. Furthermore, the correspondence course need not use the printed page as its only medium. Appropriate combinations of other media, particularly audiotapes today and video-cassettes soon, may be incorporated into a correspondence course. Thus the correspondence course, in which many of the other technologies may be incorporated, has the potential of becoming a most powerful tool which the individual may use at his own pace and convenience in pursuing the continuing education which is so essential to maintaining his professional life.

Education of the public. Most countries in the world today are being oriented towards science and technology. However, the common man is not fully aware of either the modern advances in science and technology or of the scientific analysis and solutions of man's pressing problems. It is important that chemical educators direct some efforts towards educating the citizen about the role of chemistry in present-day society. This is best done through audiovisual media. Such programmes also provide the much needed publicity that the chemical profession requires to attract adequate funds for chemical education and research from governments and funding organizations. Chemical education for the citizen is particularly important in developing countries where chemists have much to contribute to social and economic change.(76)

Keller Plan. Keller (77) propounded a new teaching method which abandons the traditional lectures and allows students to study on their own at their own pace. The Keller Plan in education has been tried in various science and technology courses and has met with varying degrees of success.(78) Use of educational technology in the Keller Plan could be of great value and it would be desirable to examine how the Plan can be supplemented by the use of various media.

Self-instruction and group resource centres. In recent years, many institutions have established resource centres where the audiovisual equipment and other tools of educational technology are made readily available to the students.(3, 79, 80) Students can use facilities in such centres under the direction of instructors. These centres are often located close to the laboratory or classrooms. There is no doubt that such centres fitted with various types of equipment would be a tremendous boon to the enthusiastic student who wants to learn fast and also to the student who is slow and may make several attempts to learn a concept. A typical centre is equipped with cassette tape recorders, slide projectors, Super-8mm films, models, TV monitor, etc.

In addition to individual learning systems, there has been some interest in using media for teaching and testing in group teaching situations. Design of buildings has undergone radical change to accommodate the various facilities required for audiovisual media and other tools of educational technology. The multi-media group teaching systems can even 'substitute' the teacher. In such situations, rear screen facilities with student response panels built into desk tops are being used. Response to multiple choice questions shown on the screen is registered on the teacher's console or linked to a computer terminal.

Resource centres for instruction of individuals or groups are expensive but highly beneficial. Resource centres run by teachers with an open-house policy could provide an atmosphere where students freely obtain assistance without any psychological barriers.

Advanced educational networks. Advanced educational networks using all media from digital transmission to colour television have been conceived, and it is suggested that such networks can improve the quality of instruction and research.(81) It has been suggested that steps should be taken by educators and governments to create such networks through which colleges and universities of all sizes can have quick access to information and can share their human, library and computer resources. It will be exciting to see how such networks will effectively be employed in chemical education.

Communication satellites. Communication satellites are one of the recent communication technologies capable of transmitting and distributing electronic information (radio, television, digital computer data) for use in education.(82) The availability of satellites to deliver signals over wide areas at reasonable cost has made it interesting to use satellite technologies in educational programmes. Countries like the U.S.A. and Canada have already advanced considerably in this regard. Countries like Brazil and India are considering putting up satellites for communication purposes. The potential of these satellites in reaching students and teachers in the remote corners of a large country is tremendous. Shortage of good, qualified teachers, and of schools can be offset to some extent by the use of satellite systems. While we cannot foresee the satellite system replacing the teacher, broadcasts from good teachers could certainly supplement or support instruction in small schools and colleges run with minimum staff and equipment.

THE ROLE OF THE TEACHER

With all the advances in educational technology, it is important to remember that the teacher can never be replaced. The role of the teacher continues to be supreme although the relative emphasis in his activities and functions may change. There is no substitute for a good teacher as far as classroom lectures are concerned.

Educational technology makes great demands on the teacher in terms of his ability to innovate. It is the teacher who still has to carry out imaginative programming, produce good slides, audio-tapes and TV programmes. In this regard it may be necessary in many instances for teachers to get adequate training in the use of educational technology. Teachers producing films or TV software may find it necessary to have proper dialogue with the managers or advisers in producing programmes.

The tools of educational technology will be popular and effective only as long as the teachers do not make the students feel that education has become machine-dominated. Student reaction surveys and evaluation of student performance are, therefore, very important in using media of educational technology for instruction. Students should continue to have the feeling that they can always call on the teacher and that machines are there only to assist them in their studies and supplement the efforts of the teacher. Advances in educational technology which increasingly dehumanize education will have very little relevance.

PROBLEMS OF DEVELOPING COUNTRIES

It is important that special reference be made to the status of educational technology in developing countries. Most schools and colleges of developing countries are poorly equipped, both in terms of physical facilities and in terms of the quality of teachers. Educational institutions in many countries do not have facilities for television or for showing films. In these places, the use of overhead projectors, cassette tape recorders and Super-8mm films are yet to be popularized. These are not expensive and are within the reach of most institutions. It is important that educational institutions in developing countries have access at least to these simple tools of educational technology in the coming decade. Preferably, these gadgets should be produced in the developing countries and made available at low cost. In the absence of computers, programmed calculators should become available in the colleges, if not in high schools. Some developing countries could get access to large computer systems and data centres located in advanced countries through satellite communication networks. It is hoped that international programmes in chemical education (76) will be directed towards this end in the near future.

SUMMARY AND RECOMMENDATIONS

Educational institutions should encourage the judicious use of the various media of modern educational technology. Institutions should encourage teachers to prepare themselves in using these media effectively. It may indeed be necessary to provide adequate training to teachers at all levels in educational technology. Such preparation or training is particularly needed if teachers are to produce software of high quality. Teachers who make worthwhile contributions in educational technology should receive proper recognition.

It is important to realize that the tools of educational technology should supplement, strengthen, and enrich the conventional teaching or learning practices, but should not in any way limit communication between the students and the teacher.

Among the various tools of educational technology, projectors, slides, films and audio-tapes can be readily and effectively employed by most teachers in most places. Television is most useful for demonstration and laboratory instruction. Video-cassettes may become common in the near future in some countries. Programmed learning is relatively inexpensive and can be effectively employed in most institutions and by most teachers. Computer assisted instruction will be beneficial and worthwhile if great care is taken to develop proper programmes that permit interactive learning; however, this medium is too expensive for most institutions. Where computers are not available, programmable calculators would serve the purpose nearly as well in many instances.

Educational institutions should freely share their hardware and software with neighbouring institutions wherever possible.

It would seem that in most countries and in most institutions tools of educational technology may not bring about basic changes in the design of curricula and courses; they will mainly enrich and enliven the learning experience of students. Self-instruction or individualized instruction through the media of educational technology will undoubtedly gain more importance in the future and teachers should exercise care to see that these media are employed in the right learning situations. In continuing education or in the Open University type of situation, television, radio broadcasting, etc., may indeed be the major components of the formal training programme.

Professional bodies (or science academies, where applicable) should act as clearing houses for information on educational technology, organize meetings of experts and users, encourage and sponsor educational research and production of software, attempt to eliminate or minimize problems of copyright, and popularize chemistry in society through use of communication media. Professional bodies should also keep in mind the needs of continuing education with regard to educational technology.

Professional journals should publish reviews on films and other software used in educational technology.

Regional and national centres should be established in all countries to promote the use of tools of educational technology in science education. Such centres could not only disseminate information, produce and distribute material, but also organize training programmes for teachers, producers and others interested in educational technology.

International programmes.

1. It is recommended that Unesco periodically publish reports or surveys on the various tools of educational technology in chemistry (in different languages) and provide all available information on software as well as hardware. Unesco/IUPAC should organize periodic symposia on this topic; it is suggested that the first such symposium be held in the next two years.

2. Unesco should sponsor production of films, slides, and other material at least on the most important basic concepts in chemistry and make them available (at marginal or no cost) to all countries and institutions. Such material can be readily reproduced in larger numbers by interested countries.

3. Unesco should do everything possible to eliminate or minimize problems of copyright on software: films, slides, etc. This can partly be accomplished by sponsoring production of some of the material by professional bodies, or by individual scientists and institutions.

4. An international centre on educational technology specifically dealing with chemistry should be established by Unesco for the dissemination of information, training of teachers, and other personnel as well as for production and distribution of material. The centre should coordinate various national efforts to minimize excessive duplication.

5. Unesco should make available advisory services of specialists to countries or institutions interested in initiating or strengthening their use of educational technology in chemical education.

6. Special attention should be given to developing countries interested in educational technology. Unesco should initiate programmes to see that educational institutions in developing countries soon have access to at least the simple tools of educational technology such as Super-8mm projectors, overhead projectors, films, and programmable calculators. Support should be given to produce such equipment in some of the developing countries, so that they become readily available and at low cost.

Satellite communication will probably be used in the near future in some of the countries for educational purposes. Both national and international efforts would be necessary to see that chemical education of students and the public through this medium is effective. Unesco should ensure that the interests of education are adequately protected.

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II. Trends in other aspects of chemical education

New approaches to the design and evaluation of chemistry courses

by David Cohen

INTRODUCTION

Should we teach simple chemical bonding at the early secondary school level? And if so, should it precede or follow the teaching of atomic structure and ionization theory? These are some of the countless decisions which need to be made during the development of chemistry curricula. This paper is concerned with examining the criteria which might be used and exploring the type of personnel who might be involved in improving the quality of such decisions and thus in improving the resultant chemistry curricula.

WHAT IS A CURRICULUM ?

An initial problem in studying chemistry curricula has arisen from the many different connotations given to the terminology. However, it appears that there is a growing consensus among curriculum theorists concerning the definition of curriculum. Increasingly curriculum is defined in terms of its component elements, namely: objectives; selection and organization of content and other experiences for students; and evaluation of student progress.

What is produced when these components interact represents the curriculum?

THE CURRICULUM PROCESS: HOW AND BY WHOM ?

The evolution of a curriculum occurs as a series of decisions. They represent choices from a range of alternatives concerning each of the components and their interactions. The curriculum process is concerned with the study of these decision-making procedures. In particular, it is concerned with the criteria used and the personnel involved, as well as with the activities, assumptions, methods and data used.

The emphases in this paper are upon an analysis of the existing but very limited literature concerning trends in the processes of curriculum development and evaluation in chemistry, including a comparison of pre-university and university processes. The paper also describes some of the emerging problems in relation to the development of chemistry curricula and suggests further action needed to improve these processes.

Studies of the curriculum process address themselves to two major questions, namely: How are curricula developed? By whom are curricula developed?

These two questions will recur in this paper as each curriculum element is considered.

The interrelationship between products and processes of curriculum development may be summarized in this way: 'Curriculum development is a process whose product is the curriculum and the process is concerned with how and by whom the curricula are developed. Curriculum process refers to the application of criteria for selection and ordering of curriculum items' (cf., Johnson, 1).

Comparisons between products and processes are illustrated in Table 1. The nature of the product is not predetermined by the process used.

Related to the 'how' question, the processes by which curricula are developed vary considerably. A key influence upon the processes is the extent of centralization of curriculum decision-making. As a result of a survey, Thompson (2) reported that it is 'the central authority responsible for the organization of the secondary school - which in most cases is the Ministry of Education' which generally determines the content for chemistry in European academic secondary schools. One tends to find that centralized national or state-wide curricula are accompanied by higher levels of prescription, especially when the curricula are reinforced

Table 1. Comparison of chemistry education curriculum products and process considerations

Curriculum component	Related curriculum product considerations	Related curriculum processes
Objectives	Sources of objectives (industry, professions, society) and their changing demands. Influences upon the objectives of chemistry education of: (a) changing nature and structure of chemistry; (b) changing nature of students; (c) changing technology. Trends in methods of expressing objectives.	How are chemistry teaching objectives determined? What criteria are used in determining objectives? From what sources are objectives for chemistry curricula derived? Who should determine chemistry education objectives?
Learning experiences and their organization	Content of chemistry courses. Trends in methods of teaching chemistry. Changes in learning materials. Influence of new technology upon the teaching of chemistry. Subdisciplines of chemistry. Sequencing of chemistry units. Interrelationships of chemistry units. Nature of student activities in learning chemistry.	How are chemistry teaching objectives translated into learning experiences? How can appropriate student activities be devised to promote chemistry education objectives? What criteria are used to help develop or select and organize chemistry learning experiences? By whom are the learning experiences devised and organized?
Evaluation of student progress	Trends in techniques of assessment of student progress.	Who is responsible for evaluating student progress? By what methods are students evaluated?

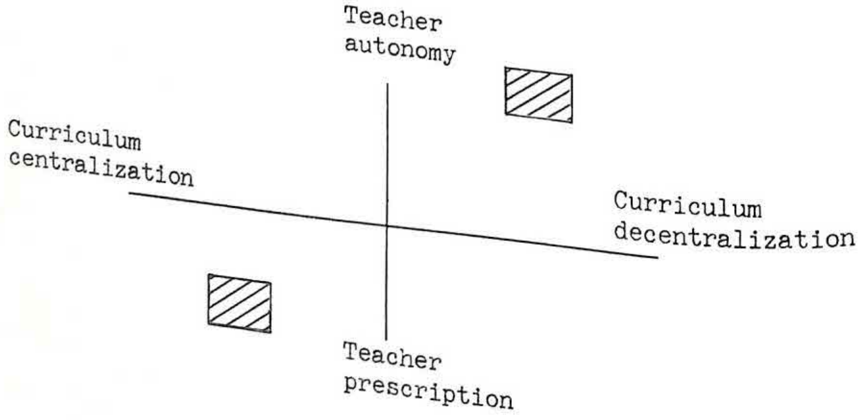

Figure 1. Relationship between curriculum centralization and teacher autonomy

by centrally imposed (external) examining. On the other hand, decentralized curricula divorced from external controls provide higher levels of teacher autonomy.(Figure 1)

Responsiveness to demands for curriculum change is likewise related to the degree of curriculum centralization. Even in highly centralized systems, minor and continuous modifications may generally be made quite informally by chemistry teachers in their own classrooms, resulting in small gradual changes. Thompson suggested that the more extensive types of curriculum change recur at seven to nine year intervals for the centralized European chemistry curricula. Student or staff pressures for more radical change (such as providing short self-teaching units or modules) and the availability of new premises or facilities or apparatus supplies are factors reported by chemistry teachers as stimuli for curriculum change.

In less centralized circumstances, curriculum guide-lines provide essential components and allow teachers to select from broad or numerous suggested alternative options and/or to add their own options. Greater degrees of decentralization rest curriculum responsibility upon individual teachers for each of their classes.

Related to the 'by whom?' question in the process of development of chemistry curricula, the personnel involved could include the classroom teacher, the university chemistry academic, the science educator, the industrial chemist, the psychologist, sociologist and philosopher, students, and lay members of the community. It might be an intuitive one-person curriculum effort or the outcome of a complex process of interactions between members of a project team or of the activities of committees and subcommittees.

INDIVIDUAL CURRICULUM COMPONENTS

Hereafter, the paper will be presented successively in sections under the headings: the processes of developing objectives, learning experiences and their organization, and evaluation of student progress. This is certainly not intended to imply that these elements are the products of a sequence of separate curriculum processes. Within each section, the 'how' question will be reviewed through a study of the criteria available for reaching decisions and the nature of personnel involved in making the decisions will also be studied.

Determining the objectives of chemistry education

Objectives represent value judgements, or an ordered set of priorities for teaching. Thus, diverse sets of objectives for chemistry education may exist side-by-side, with equal claims of 'correctness' provided that they are based upon equally well-considered scales of values. Such objectives may be developed through the application of one or more of at least three approaches: scientific analysis; philosophical analysis; and/or human intuition.

The products of such approaches are the objectives which are considered by Frazer* and these are summarized for seven European countries by Thompson.(3) The processes by which chemistry education objectives have been determined may be studied through the questions how? (what criteria should be employed?) and by whom? (or what personnel and procedures are and should be involved?). These questions will now be examined in turn.

Criteria

Goodlad and Richter (4) listed a number of criteria against which to validate the selection of objectives. These were:

1. Validity (in terms of societal, professional and industrial needs)
2. Relevance (in terms of the changing characteristics of students)
3. Appropriateness (in terms of our increasing knowledge of psychological processes)
4. Precision (in terms of the specificity with which they are expressed)
5. Comprehensiveness (in terms of their coverage of the intentions of the curriculum development agencies)
6. Consistency (in terms of their internal supportiveness and lack of contradiction)
7. Feasibility (in terms of availability of facilities, personnel and costs for implementation)

These criteria will now be illustrated in sequence, beginning with the validity criterion. The National Science Foundation deliberately sponsored courses which promoted the value of the processes of inquiry as characteristic of the sciences, by contrast to the static body of knowledge approach which characterized their predecessors. It was assumed that the objectives of school chemistry should mirror the work of the professional chemist, and CHEMStudy director Campbell (5) indicated this same intent for his project, stating: 'A chemist is a person who makes experimental observations and then interprets them in terms of atoms and molecules and their behavior. The CHEMStudy course is planned to allow even first-year students to utilize the same approach and conceptual treatment.'

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*See chapter 'Up-to-date and precise learning objectives in chemistry'.

Nor was CHEMStudy unique in these emphases upon objectives. Eshiwari (6) found from his comparative analysis that there is 'little difference' between the objectives of CHEMStudy and Nuffield Chemistry. Goodlad (7) treated the objectives of both CHEMStudy and the Chemical Bond Approach (CBA) conjointly, stating: 'Objectives of the programs appear to rest on the assumption that any significant behavior which can be derived from analysis of an academic discipline can be learned by students of a given age and is, therefore, worth learning.'

The validity of such an assumption, and therefore of the objectives themselves, bears critical examination. Should the school student's chemistry mirror that of the professional chemist at work in his discipline, for example? Other questions are raised in relation to the possible distortion of values which the above philosophy may endorse. In this respect, a study of Meyer (8) is suggestive of important and unintended outcomes. Based upon his study of the scientific attitudes and interests of Nuffield-science educated fifth-formers, Meyer found that Nuffield O-level chemistry 'promoted positive affective change.' However, he warned that Nuffield courses tended to over-emphasize direct experience at the expense of other problem-solving techniques - especially the use of printed materials and questioning of teachers. Additionally, Meyer's evidence led him to suggest an erosion of interest in fine arts and literature concomitant with higher interest level in Nuffield chemistry courses and to question this trend in objectives from 'equally important values'.

The question of relevance of objectives calls for a consideration of students in today's world - their social mores and their environment in a technologically complex age of rapid change.

On the criterion of appropriateness of objectives, psychological readiness of the learners is paramount. In this connexion, the emphasis of secondary-school chemistry curricula upon chemistry as a discipline has been denounced by Smith (9) as a 'kind of precocious role playing'. As an example, ability to understand abstract chemical theory demands a particular level of concept development.

The precision of an objective is stressed in order to remove ambiguity. An objective stated as 'the development of practical skills' is not specific enough to help the teacher develop appropriate laboratory activities, whereas a quite precise objective might read: 'to develop the ability to run 10 ml of liquid from a burette to within an accuracy of 1 per cent'.

Relating mainly to the criterion of comprehensiveness, some of the criticism of current chemistry curricula has been based upon an alleged neglect of objectives concerned with the personal, social, economic and moral implications of chemistry, and with the impact of chemistry on society. For example, in a position paper prepared for the Curriculum Committee of the American Chemical Society, Cassidy (10) blames over-concern for content for the neglect of communication and of 'personal problems of the students in learning the meaning of science and sensing its power to strengthen their lives'.

A key problem arises in terms of the consistency criterion between the objectives of chemistry education. In fact, Klopfer (11) nominated as the basic current dilemma in science education generally - and certainly the same applies in chemistry education - the incompatibility between scientific literacy objectives as needed by all citizens and pre-professional science preparation as needed for scientists and science-related professions. The dilemma is not one unique to the U.S.A.; Davenport (12) attests to the same problem in India. He predicts resolution of this dilemma by 1990 through the creation of two distinct curricular streams at both secondary and tertiary levels, designated as 'prospective scientist' and 'scientific literacy' streams.

One approach to solving Klopfer's dilemma has been attempted by the High School Subcommittee of the American Chemical Society Curriculum Committee.(13) Broad general agreement was found possible for high school students concerning the topic areas and depth of study for chemistry education. (The eight areas included atomic theory, bonding, and acid bases) Within each area, three-level hierarchies of 'performance objectives' - for non-science terminal high school students, for non-science, college-bound students and for potential science college students - were developed.

In relation to the feasibility criterion for selecting objectives, the development of many laboratory skills found suitable for developed countries may prove unfeasible for developing countries due to the lack of laboratories, facilities, equipment or personnel.

Personnel and procedures

The question: 'What personnel and procedures are and should be involved in determining chemistry teaching objectives?' is a complex and crucial one. It implies that objectives are explicitly developed and stated, which in practice is often not the case. In centralized educational systems and where objectives are stated, decisions may be legislatively prescribed. They may be the outcome of the labours of but one person (e.g. an inspector within an Education department or a professor). In other cases, they may involve a few people, or a team or otherwise large group.

The literature about the nature of the personnel who have been involved in any aspect of curriculum decision-making is despairingly sparse. Documentation of the roles played by participants is virtually non-existent. Arguments which appear valid have been proposed for including teachers and other educators, chemists of various sub-disciplines, psychologists, sociologists, philosophers, students and community members.

Data for a preliminary survey by Cohen (14) of the processes of chemistry curriculum development in several countries suggest certain broad trends: university undergraduate level chemistry courses are developed without any apparent concern for the published processes of curriculum development. They are generally the outcome of the labours of one to four chemistry academics, occasionally assisted by an educator or psychologist, and usually produced through monthly meetings held after 4 p.m. or through weekly lunch-hour meetings. Decisions are invariably reached through consensus rather than voting. Objectives for tertiary chemistry curricula are generally stated only in broad terms and rarely are they prespecified for use in subsequent stages of curriculum development. These preliminary findings tend to confirm other reports in this area. For example, in Bryant and Hoare's study (15) of Australian first-year university chemistry courses, they reported that 'too frequently the aims of a course or topic (where these are set out at all) are expressed in vague generalities'. To promote communication through accurate specification of course objectives and performance expectations, the General Chemistry Sub-committee of the American Chemical Society Curriculum Committee has developed sets of performance objectives related to 12 broad topic areas for broader science-oriented undergraduate general chemistry courses.(16)*

Where objectives have been perceived at tertiary level as being useful, the Cohen survey suggests that they have been mainly influenced by 'the expansion of chemical knowledge', and to a lesser extent, by the needs of the chemical industry, recommendations of professional societies, and interests of students.

The Cohen survey also indicated that, at secondary level, chemistry courses tend to be produced by large committees comprising mainly high school chemistry teachers, especially ministry-initiated curriculum groups, sometimes even including university chemistry academics. Exceptions include publisher-sponsored developments, in which two or three academics are usually involved in a text-book oriented task. They generally meet weekly for about three-hour time blocks, often starting after school.

As with tertiary curricula, decisions are almost always reached by consensus, but unlike university curricula, objectives are generally specified before and during curriculum development. In many cases, the objectives are both stated explicitly in broad terms and also developed as specific objectives. The secondary school chemistry objectives are influenced heavily by the requirements of university or accrediting agencies and by external examination requirements (where these exist), and are tempered by known student interests.

A major exception to the above procedures is illustrated by 'curriculum project' operations in the U.S.A., in the post-Sputnik decade. In the CHEMStudy programme in the U.S.A., very broad objectives had been submitted in the original proposal to the National Science Foundation (e.g. 'to diminish the current separation between scientists and teachers in the understanding of science' 17). These objectives were presumably developed by the Garrett Committee of the ACS. The First Planning Conference for CHEMStudy comprised college professors of chemistry of 'proven writing ability .... No attempt was made to include professors of education or curriculum specialists'.(18) There is no description of the procedures for developing objectives in *The CHEMStudy Story*, but rather a concern for the content of the textbooks and other materials being prepared - although the agenda for the first meeting of their Steering Committee listed objectives as one of the items which 'seem to need most discussion'.(19)

In his perceptive summary of the corresponding changes in the processes of curriculum development which embraced both the Chemical Bond Approach (CBA) Project and CHEMStudy, Hurd (20) documents the transition from educators to scientists of curriculum development personnel. A corresponding change in process was from the 'objectives → subject matter' approach of educators, to the scientists' process of 'chemistry as a discipline → students as chemists' approach. This approach relied upon the intuition of the scientists to reflect the discipline within the written materials of the curriculum. The objectives were then written retrospectively, based upon the completed product, 'in terms of conceptual schemes and inquiry processes'. Content selection by the scientists thus arose directly from the discipline, without consideration of social or individual needs.

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* See chapter 'Up-to-date and precise learning objectives in chemistry'.

The relative neglect of systematic processes for developing or studying chemistry education objectives in recent times is in marked contrast to the flurry of activity half a century ago. For example, Powers (21) analysed statements from textbooks, chemistry courses and educational periodicals 'in an effort to determine the recognition given to sociological, psychological and subject-matter objectives in various sources'. A Committee of the Central Association of Science and Mathematics Teachers under Osborne (22) surveyed chemistry teachers to ascertain their agreement with objectives in a list of nearly 100 statements; the Committee of Chemical Education of the American Chemical Society received 30,000 criticisms of its tentative outline of chemistry objectives. (23) Wray's doctoral study (24) used a wide range of respondents in a sample of 100 people, all with a minimum of one year of high school chemistry, to rate the importance of 1,550 items of chemistry information in relation to usefulness and pleasure activities. The Curtis Digests (25, 26, 27) represent an invaluable source of many other similar studies.

One more recent use of a more systematic approach to the development of chemistry objectives is illustrated by the Whitfield study.(28)A jury of 30 experienced chemistry teachers arbitrated upon a list of objectives - through the coordinating theory of an electronic approach - for teaching organic chemistry and then ranked them in order of importance.

A study by Cohen (29) assumed that those scientific attitudes worthy of inclusion in secondary school science curricula were those which would be agreed to by a group of eminent scientists. Fifty-eight scientist-members of the Australian Academy of Science rated 230 statements (culled from the literature of science and of science education) into nine categories according to their relative 'essentialness' as components of the scientific attitude. On 26 of the statements, a high degree of consensus was reached. These reflected initial speculative, inventive and investigative approaches, followed by great concern for rigorous checks and verification.

However, these studies are isolated examples of an apparent lack of current concern about the processes of developing objectives for chemistry curricula.

Selection and organization of learning experiences

The term 'learning experiences' is used by curriculum theorists to include all the experiences of the learner, including the content to be studied, the student activities, and the materials used for learning. (Many writers use the term 'syllabus' synonymously with 'learning experiences'.) Laboratory experiments, research projects, field work, demonstrations, audio-tutorials, and simulation activities are a few examples of learning experiences.

The organization of learning experiences includes consideration of the divisions and interrelationships between the experiences, their sequencing, the rates of learning, and the learning materials through which experiences are presented.

The two key questions to be examined in this section are:

- What criteria are or should be used in selection and organization of chemistry learning experiences;
- What trends are evident in the current approaches to selection and organization of chemistry learning experiences.

Criteria for selection and organization of chemistry learning experiences

Analyses of the contents of chemistry curricula suggest that, provided an outline of general chemistry topics is sufficiently general and lacking in specified sub-divisions, a high degree of consensus can be obtained concerning these contents.

At the more specific level, evidence shows an extremely wide diversity in both the levels of sophistication and the precise content.(30) In fact, as a result of an analysis of the notebooks and laboratory records of first-year university chemistry students at all Australian universities, Bryant and Hoare (31) found that 'there was no single topic which was covered at all universities', and there was considerable diversity between the topics studied. A vacillation in emphases between descriptive and 'principles' chemistry in basic courses was referred to by Gómez-Ibáñez (32) at the previous International Symposium on Chemical Education. Perhaps these findings are not unexpected, in terms of the influence of subjective factors upon content selection procedures. Hammond (33) assesses the situation in this way: 'One man's fundamental principles turn out to be intellectual garbage to another, and vice versa'.

Nevertheless, isolated attempts to place the selection of content on more scientific bases continue. For example, Margenau (34) attempted to develop helpful and interrelated criteria. These included conciseness and internal consistency, universal applicability, and interrelationship within a logically-related network of concepts.

Raven (35) reminds us that these criteria may have differing levels of importance according to whether students are at primary, secondary or tertiary levels of education.

The CHEMStudy writing team used a rather simpler approach to select their content, using the following criteria:

1. Is the idea so important that no first course is complete without it?
2. Can the idea be developed honestly at a level comprehensible to high school students?
3. Can it be developed out of experimental evidence high school students can gather, or, at least, understand?
4. Does it tie into other parts of the course so its use will be reinforced by practice? (Hurd 36)

Bruner (37) has espoused the use of structure of knowledge as the criterion for content selection on the grounds that 'it simplifies information, generates new proportions, and increases the manipulability of a body of knowledge'.

Such an approach was followed by the Chemical Bond Approach (CBA) Project, and the major concepts embodied in that project are illustrated in the paradigm reproduced as Figure 2.

In fact, CHEMStudy and CBA utilized integrating themes. CHEMStudy content contains three sections - the chemist's framework of 'the importance and limitations of the experimental approach and the need for building scientific models such as the kinetic theory and the periodic table', the development of the atomic model through the laboratory, and the application of the principles developed to the study of descriptive chemistry.(Merrill 38, 39) The CBA course has the theme of chemical bonds, or characteristic structures - this idea being developed through 'the use of geometry in chemical reasoning'.(40)

In Ontario, Canada, a new grade 12 chemistry course was introduced in September 1967 'to create an understanding of the subject rather than to provide material to be memorized'. It was accompanied by a detailed teaching outline prepared by 75 teachers, with university and Department of Education support, in a two-day workshop, and included references to CHEMStudy material and an understanding of its philosophy of the interrelationship of experiment and theory and stress upon underlying principles. This course was to become an introductory course to another introductory course, since a modified form of CHEMStudy was introduced in grade 13 one year later.(Leonhardt 41)

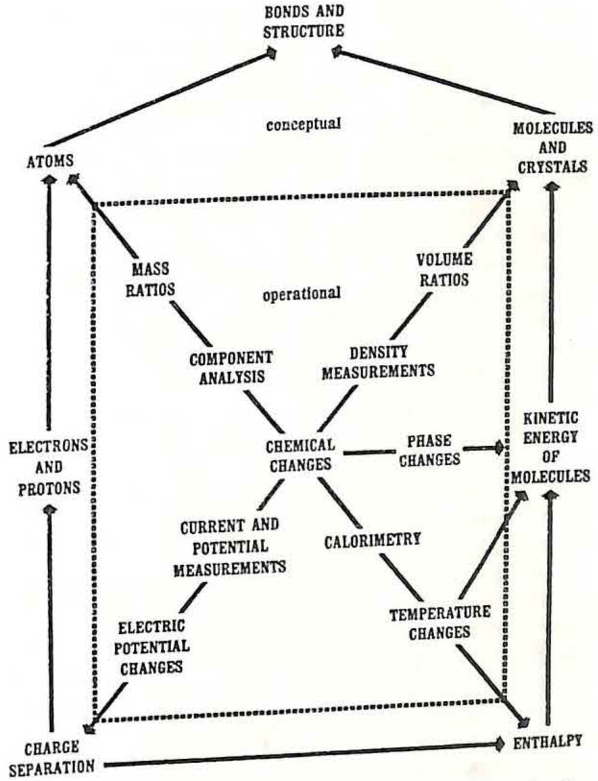

Figure 2: Chemical Bond Approach Project content paradigm

Whereas ten of the above eleven criteria of Margenau, Hurd and Bruner reflect concern for chemistry as a discipline, only one of those criteria relates to the learners. In hindsight, one need not be surprised about the conceptual problems which arose in the scientist-generated projects. As a corrective, it has been proposed that Piaget's sequence of conceptual development stages in children be used as a screening device for teaching certain concepts in chemistry.(Shayer 42) In fact, based upon an analysis of the conceptual stages, modifications of sequencing and integrating themes are suggested for the Nuffield O-level chemistry course .(Ingle and Shayer 43)

The development of chemistry curricula containing learning experiences which show greater concern for relevance to the learners is discussed more fully below.

On the question of sequencing, various arguments are proposed concerning why one topic should be a pre-requisite for another. Traditions have often developed into dogmas. There is probably no valid evidence to contradict the assertion that the most appropriate learning sequence is that which relates to the spontaneously-emerging interests of the students - an approach increasingly recognized by the modular or unit approach to developing curriculum materials and audiotutorials.

A related issue is whether topics should be studied once only, in depth, or whether the 'spiral' approach to curriculum organization is more effective. In their study of Australian first-year university courses, Bryant and Hoare (44) found that the approach which predominated was a broad initial superficial coverage, followed by a greater-depth repetition later.

More than a decade has now passed since courses such as CHEMStudy and CBA Project were introduced. Critics now claim that the courses were more appropriate for the gifted or science-oriented student and that the improved scientist-injected content and structure has not been matched by correspondingly improved attitudes or enrolments. New concentrations of activity upon chemistry curriculum development are occurring.

An isolated study at university level with implications for selecting and organizing learning experiences is that by Ring and Novak. (45) This showed that chemistry achievement was enhanced by curricula which took account of long-term transfer of pre-existing cognitive structure and subsumers. In an attempt to improve existing criteria, the American Chemical Society through the Curriculum Committee of its Division of Chemical Education, has established eight sub-committees according to chemistry subdisciplines (e.g. analytical, biochemistry, inorganic). These subcommittees are addressing themselves to such considerations as identification of key topics, development of recommended outlines, relationships with other areas, instruments important for curriculum inclusion, and the development of behavioural objectives.

Student unrest in some countries, critical evaluation by staff in some and declining chemistry enrolments in others all appear to have made revisions more urgent. Whatever the causes, the literature of chemistry education is liberally announcing changes on a broad front in the nature and organization of learning experiences.

Trends in the processes of selection and organization of learning experiences

Course planners have responded to staff and student pressures by seeking alternative sets of learning experiences and by using alternative methods of organization. One of the current status symbols of chemistry education is 'relevance', as reflected in the Education in Chemistry '72 Mt. Holyoke Conference of the American Chemical Society. Several of the processes undergoing trials may be seen as helping to promote relevance. The major identifiable trends include:

1. Interrelating chemistry experiences with other areas (e.g. physics, biology, geology) and in some cases creating new topics or new 'subjects' such as in biochemistry (e.g. synthesis of life) or geochemistry (as interest in space exploration and environmental conservation expands);
2. Elimination of outdated or isolated specific factual material and replacement by updated chemistry concepts of broader significance;
3. Restructuring of chemistry courses to better reflect the activities of contemporary research chemists;
4. Extension of traditional range of chemistry topics to relate more to life in the 1970s, through diversification of learning experiences; inclusion of career-relevant skills; and reemphasis of chemistry as a human endeavour;
5. Diversification of teaching methods, with decreasing emphasis upon lectures and increased use of small-group learning and individualization, of tutorials, and of research-oriented activities.

These trends will now be successively illustrated by selected examples.

Interrelationships with other areas. Integrated science has been described as 'non-disintegrated science'. In attempting to grapple with life's realities, a scientifically literate citizenry knows not the barriers of the disciplines. Thus, integration will help to restore science to the state in which it can be most relevant to the daily needs of the majority of citizens. There is a significant trend towards the teaching of integrated science (cf., Richmond 46).

One such high-school programme is known as the 'Chemistry Teaching Associate (CTA) Program', directed by Gardner.(47) Its stimulus is an innovative approach to chemistry curriculum improvement at the University of Maryland which has helped to re-integrate the separate areas of chemistry. The programme involves bringing experienced high school chemistry teachers (up to ten) to the university to spend an academic year as temporary members of the university's chemistry staff and concurrently, to work with permanent staff in the pursue of post-graduate studies. The CTAs have helped revise the undergraduate curriculum, integrating formerly separate units and developing new laboratory programmes and materials. Concomitantly, communication between staff and students has been improved and atypically, sharply increased enrolments have been observed in the undergraduate chemistry programme.(48)

The CTA participants have cooperated with university chemists in developing what is known as the Interdisciplinary Approaches to Chemistry (IAC). It was expected that IAC would have been used by nearly 1,000 teachers in 1973-74. The course comprises a series of flexible interdisciplinary modular options which can be selected and sequenced according to the needs and interests of teachers and students. The broadest module ('The Delicate Balance') draws upon the areas of geology, meteorology, oceanography, chemistry, physics and biology.

The trend towards integration of chemistry with physics or other areas at first-year university level in the U.S.A., has been directed mainly towards non-science majors. The PSNS (Physical Science for Non-Science Students) course focuses upon the study of solid matter - its origins, properties and investigative techniques. Ideas incorporated into PSNS include 'the beauty of the orderliness and self-consistency of the Universe', and 'the power of the technique of making models, both physical and mental'.(49)

In the American three-college Joint Science Department of Harvey Mudd College, Pomona College and Claremont Graduate School, a one-semester integrated physics-chemistry course has been followed for five years by a concurrent (physics + chemistry) second semester course. The first semester is team taught by a physicist and chemist providing both viewpoints on topics such as quantum mechanics and thermodynamics.(50)

Elimination of outdated or isolated material and use of broader concepts. A major criticism of the secondary-school science curricula of the late 1950s was that 'the content ... does not accurately recognize scholarly advances in these fields'.(51) As an attempted corrective, the Course (Content Improvement) Program of the National Science Foundation in the U.S.A., sponsored efforts of teams in 'the development of courses and instructional materials that reflect contemporary scientific knowledge and points of view' (52) - a quite specific effort to update chemistry curriculum content at secondary-school level.

As described above, integrating concepts were adopted for both CHEMStudy and the CBA Project. Perhaps a problem with these arose from the sophistication of the integrating concepts.

Adverse criticism of Nuffield Chemistry Project omissions has been levelled by Fowles. (53) His description of the omission of the study of 'the equivalent' as potentially damaging to the needs of industry was only one of his criticisms in an outspoken attack upon Nuffield Project chemistry materials. Largely in response to Fowles' criticism, Halliwell (54a) replied that the Nuffield Chemistry Project development team sought to develop 'flexibility of treatment within a framework of objectives'.

The reduction of teaching of factual material in Nuffield Chemistry has also had other adverse reactions. For example, Bradley (54b) has been strongly critical of the Nuffield O-level chemistry course, including the following specific criticism about the course content: 'What the student needs is more experience of fact than he was given in 1920; with the Nuffield scheme he will get less... The omissions of both fact and theory by the Nuffield authors are very bold. They are such as to leave a damaged and patchy scheme which could not lead to sound chemical knowledge'.

Some pruning has also been advocated at university level although the concept of integrating themes appears not to have been extensively used. A reduction in the number of topics and increased emphases upon historical, philosophical and sociological aspects of freshman chemistry courses are proposed by Gorman.(55)

A method for both eliminating unrelated material and resequencing topics is based upon an analytic approach developed by del Rio et al.(56) at the Universidad Autonoma de Guadalajara. An n x n table is produced from the 'n' items developed through a breakdown of topics into specific items. By a process of elimination, the immediate prerequisites for each item are reduced to a small number, and a network of alternative sequences is synthesized. Each item is assigned a teaching time, and the total time is reviewed and revised against the total time available. Alternative courses parallel the alternative sequencing of items. Claims include time economies and improved student understanding of the logical sequencing.

Restructuring chemistry curricula. Traditionally, the conceptual organization of undergraduate chemistry courses has been built around what Hammond (57) has described as a confusing ritual of terminology: organic, inorganic, physical and analytical. Hammond proposed the consideration of alternative subdivisions (such as structure, dynamics and synthesis) which would both remain consistent with the activities of chemical scientists and still present chemistry as being 'coherent and logical in its overall orientation'.

A similar type of restructuring followed an external evaluation committee's report of doctoral programme students at the University of Minnesota. As a result, there is a trend in chemistry theses away from the traditional divisions of analytical, inorganic, organic and physical chemistry, towards integrating up to three areas such as biological chemistry, chemical dynamics, chemical instrumentation and analysis. A corresponding change has occurred in the nature of the doctoral courses offered. (58)

Extension of traditional range of topics.

(a) Diversification. By contrast to the elimination or consolidation of chemistry learning experiences, there are concurrently moves to diversify their nature. At secondary school level, a course has been introduced in South Australia for teaching about polymers and their industrial applications,(59) and another has been developed based upon teaching industrial laboratory techniques through individualized instruction and laboratory experiments.(60)

Emphasizing the important practical aspects of chemistry in our daily lives, an introductory high-school organic chemistry course (61) includes a study of structure, nomenclature and reactions, and is restricted largely to providing background to studies of such materials as petroleum, soap, and polymers.

In tropical Africa, attempts to increase relevance have been effected through the injection of local examples of chemical industry - ranging from the manufacture of the key fuel (charcoal), to fermentation and distillation of local spirits and extraction of fertilizers. (62)

At university level, the change in emphasis from the abstract theoretical to the more applied aspects of chemistry is the basis of the Chemical Technicians Curriculum (Chem Te C) Project developed under Pecsok at UCLA and piloted at 12 colleges in the U.S.A. The course arose from the findings of an ACS Committee, which led first to the establishment of an ad hoc technician curriculum committee, and then to a 17-member steering committee which included representatives of academics, industry and government, with funding from the National Science Foundation. The 28 to 30 unit course is designed for average American high-school graduates and sidesteps the need for intensive backgrounds in mathematics or chemistry.(63)

(b) Career-relevant skills. Glanville (64) has highlighted the need for courses to develop career-relevant skills. Graduates from advanced degree programmes in chemistry would be better equipped if they undertook courses such as patent law and chemical ethics, principles of chemical engineering, chemical economics, sales and marketing in the chemical industry, and management and human relations.

In many Australian universities, separate strands are developed according to the career intentions of students, and the students may be guided into medical, dental, or engineering chemistry (cf., Bryant and Hoare).

(c) Chemistry as a human endeavour. A one-year course built around carbon compound chemistry for high-school non-science majors was developed by Novick as part of his doctoral dissertation in Philadelphia. Its aims were 'to help students understand the relation of chemistry to some of today's social concerns and to promote student interest in the study of chemistry ...' The approach 'emphasizes the impact of chemistry on society instead of the structure of chemistry.'(65)

A university-level interdisciplinary course with objectives showing vital concern for the learners is the PSNS. This course arose from a 1963 conference jointly sponsored by the Advisory Council on College Chemistry and the Commission on College Physics. By 1969-70, the number of colleges and students using PSNS rose to peaks of 150 and 12,750 respectively. The objectives were oriented towards convincing students that science was fun, making them more confident (and less anxious) about science, and developing an understanding of physical science as a human and research-oriented pursuit.(66) An emphasis upon 'chemistry as a human activity' has also been the basis of injecting relevance into a first-year chemistry course for non-scientists at the University of South Florida.(67)

(d) Diversification of teaching methods. The relative inefficiency of the lecturing method for many students and most objectives is being increasingly recognized. In many universities, alternatives have been devised. At Macquarie University in Sydney, there are no formal lectures in chemistry. Dependence is placed upon study guides which direct students to detailed readings in selected reference books, and also provide assignment activities. These methods are used for both internal and external (correspondence) students. Extensive tutor-student interaction in small groups is promoted in specially-designed laboratory spaces. Additionally, there is close cooperation between chemistry and library staff in the development of special projects.(68)

Comprising a series of programmed instruction units and concurrent laboratory activities, the Keller Plan represents a self-pacing packaged curriculum approach, monitored by tutors with small groups of students. Having originated at the Massachusetts Institute of Technology Physics Department, it is now used for teaching chemistry at many American universities, including the University of Wisconsin.(69)

Reflecting the increasing need for facility in handling the exponentially mushrooming volume of chemical literature (in the late 18th century, the two-volume *Elementa Chemica* written by the Dutch chemist Boerhaave and containing a total of 1433 pages, included all the chemistry known in the world; now *Chemical Abstracts* provides abstracts of about one million new publications in chemistry each year), a course based upon a review of the chemical literature has been developed for undergraduate chemistry students.(70)

An attempt at individualization in chemistry is the honours year at Southern University in Louisiana. At their first meeting students supply background information and details of interests, and receive details of regular lectures covering chemical principles. Students complete individual assignments and then must complete mastery tests.(71)

A greatly increased emphasis upon inquiry-oriented laboratory is often coupled with individualized research tasks. For example, at Carnegie-Mellon University in Pittsburgh, a two-year integrated laboratory programme was developed following guidelines of the ACS Committee on Undergraduate Training. The programme blended the traditional subdisciplines, stressed inquiry techniques and therefore promoted individual performance, and simulated a chemist's research activities.(72)

At Colgate University in New York, students participate in a weekly research seminar and in a laboratory-seminar programme. Of the 48-week laboratory programme, 17 are spent in required basic competency activities and 6 in restricted-choice activities. The remainder may be selected and sequenced by the students themselves from a wide range of options, many located at pre-established experimental stations, and some in which students work in staff research projects.(73)

Illustrating another teaching method, some universities in the U.S.A. are using an interim term to provide short-term chemistry research activities. At Austin College, Texas, science majors may undertake one of two courses: an organic instrumentation course (basic to solving structural problems) in which a series of lectures introduce students to four types of spectrometer, followed by an application period to gain experience, and then spectroscopic analyses of increasing complexity of several unknowns. The other course is to introduce students to techniques and instruments of inorganic chemistry via laboratory investigations. Typically, students (in groups of two or three), begin with a three-day library preparation, and spend 40 to 50 hours per week for a month in completing three projects (with about half-time spent in the laboratory). (74)

As the core of the doctoral programme in chemistry, the 1972 Report of the ACS Committee on Professional Training recommends there should be a 'preparation of the student to conduct scientific research in the field of chemistry', in particular through the thesis as a significant contribution of the student. Renewed emphases upon the importance of the use of increasingly sophisticated equipment, evaluation of the development of imagination, self-reliance and adaptability, are other recommended trends.

Echoing a concern about courses for students at masters and doctoral levels, Newman (75) argued that advanced courses should be built around staff interests in order to develop laboratory proficiencies. Otherwise, students become deprived of techniques less frequently encountered at undergraduate levels.

At the secondary-school level, through the development of texts, laboratory manuals, teachers' guides and films, both CBA and CHEMStudy sought to change the emphasis 'from the descriptive-memorization-regurgitation approach to the question oriented-inquiry-experimental approach'.(76)

In summary, one can look somewhat optimistically at the extent and diversity of innovation in the selection and organization of chemistry learning experiences. More effective communication about the nature of these innovations, and a confidence derived partly from adequately-conceived evaluations of them, should help to ensure wider-scale adoption of those experiences with greatest claims to effectiveness in specific contexts.

Curriculum evaluation in chemistry education

Curriculum evaluation is concerned with gathering, analysing and reporting, and interpreting data so as to improve decisions about the components of curriculum (that is, about the objectives, learning experiences and their organization, and evaluation procedures used in assessing student progress). A systematic study of the processes of curriculum evaluation in chemistry therefore inevitably includes a review of the trends in the types and content of the various forms of chemistry assessment. A thorough review of these forms is the subject of another paper in this symposium * (see Ashford).

The processes used in evaluation are referred to as the reflective, formative, and summative stages, respectively used before and during development, and after implementation of the curriculum.(77)

Reflective evaluation

This occurs at the preliminary planning stages of curriculum development and comprises a screening of the curriculum components (through the use of mental reflection) to evaluate their suitability. It is mainly a subjective process, embodying the selection and application of criteria and use of expert opinion, and including insight and hunches. Such data (disparagingly referred to sometimes as 'soft data') may indeed appear as anathema to the scientist used to handling precise physical measurements.

Thus, one might ask for judgements about chemistry curricula before implementation such as: How important is the objective using an approach and conceptual treatment similar to a chemist? Should there be separate sets of chemistry learning experiences for students majoring in science and those who are not? Is the Watson-Glaser Critical Thinking Appraisal likely to be an instrument sensitive enough to detect changes resulting from the teaching of CHEMStudy?

There is a dearth of evidence of significant recourse to reflective evaluation in chemistry curriculum development. There have been few reported discussions, debates or studies which provide data and guidance to those entrusted to making the basic preliminary decisions about directions in which chemistry curricula should proceed. Fundamental questions of philosophy (e.g. chemistry students as chemists or citizens? which students? which teachers?) have hardly received the level of objective and scientific debate which may have been expected from groups of scientists. Ad hoc decisions often involving sharp vacillations of existing practices, and frequently reached by small groups of key policy-makers, have had far greater influences than rational discourse. The need continues to exist for regular inter-disciplinary discourse, involving chemists with teachers and other educators, philosophers, sociologists, psychologists, students and the community. Such discourse is prerequisite to effective reflective evaluation of curricula.

Formative evaluation

This takes place during the developmental stages of a curriculum (that is while the components, units or materials are still explanatory and fluid) and may lead to course improvement through progressive modification of any curriculum component. The process of formative evaluation may occur as part of an organized pilot trial, or by quite informal observation. Feedback may be derived from teachers, students or other observers, and from written or other visual or oral data.

The materials associated with the CBA Project and CHEMStudy were subjected to extensive and costly trials and revisions during their developmental stages, and the details of these procedures and their influences upon subsequent revisions are documented in the *Project Newsletters*. However, such evaluations have rarely, if ever, been matched by centralized institutional curriculum developments, where *fait accompli* committee efforts are frequently regarded as being implemented simultaneously on system-wide bases by administrative edict, and without adequate pilot studies of effectiveness. The cost of such procedures - or lack of them - in terms of lost generations of confused students is neither assessable nor measurable. A hint at the enormity of the problem is suggested by a study in Scotland. Although conducted 10 years after the implementation of the Scottish chemistry curricula, survey studies by Johnstone et al., (78) of graduating high-school students raise crucial formative-evaluation type questions concerning previously unanticipated and undetected high levels of difficulty and low levels of interest for several chemistry topics. One wonders how many comparable but undiscovered situations exist world-wide, with resulting lifelong deficiencies in levels of student understanding concerning key concepts and topics.

The same situation is undoubtedly true at university level - although the effects might be perceived as less serious since curricula tend largely to be restricted to individual institutions. A relatively easy method for obtaining formative evaluation data is provided by a significant variation of the typical student end-of-course evaluation which was introduced at the University of Minnesota.(79) This involved more frequent and improved levels of communication between instructors and students, through questionnaires administered in the first week and mid-term, and through the establishment of small-group student-faculty committees which met weekly. The continuous flow of additional feedback helped instructors to modify their programmes, gave students greater feelings of involvement in their courses, and improved faculty-student relationships.

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* See chapter 'Improved techniques of assessing student achievement'.

The need for more serious consideration of methods of conducting formative evaluation in order to obtain progressive feedback during curriculum development stages - even if only with very small numbers of students of varying ability - remains a crucial though neglected one.

Summative evaluation

This is concerned with the systematic evaluation of the broad, overall effects of a curriculum (or parts of it), after its implementation. Depending upon the criteria selected, summative evaluation can provide the potential user with a prognosis of possible effects of adoption of the product; for example: How much will it cost to implement CHEMStudy in 20 schools with total enrolments of 1,400 students in chemistry? What teaching strategies should be used to enable 90 per cent of first-year university students to master a designated set of chemistry laboratory techniques within one university term? Is the new curriculum effecting the positive changes in attitudes towards chemistry which it sought to do?

Probably more summative evaluation studies have been undertaken in the last decade of the American 'alphabet soup' curricula (CBA, CHEMStudy, PSSC, BSCS, etc.) than have been conducted for all other curricula in existence. Perhaps because of the billions of dollars invested, politicians and educational leaders were acutely sensitive to the pressures of accountability.

One of the dangers inherent in such summative evaluation was the expectation of an answer to the omnibus question, 'Which curriculum is better - the old or the new?' This type of question is unanswerable through research, since it asks for both data and value judgements simultaneously.(80) Curricula have different objectives - (one may select which curriculum to adopt upon this basis). In an early study involving students from CBA, CHEMStudy, and 'traditional courses' curricula, Heath and Stickell (81) commented soberingly that their 'results are what one would expect. CHEMStudy and CBA students score higher than the corresponding control group students on the tests which were designed for the experimental courses, and control group students were superior on the basis of the test designed for traditional courses'. So, reflective evaluation concerned with which objectives are 'most worthwhile' must precede judgements based upon summative evaluation.

Despite the cautionary note about their potential usefulness, summative evaluation studies have been proliferated, and many of these have related to the effects of CHEMStudy and CBA Project curricula. For CHEMStudy, alone, Ramsey (82) compiled a comprehensive review of both the 'subjective' and 'objective' literature of CHEMStudy for the ERIC Science Education Centre. Although the focus of the research which he reviewed was upon comparisons with traditional courses, Ramsey pointed to the need for studies concerning how and with whom CHEMStudy works best.

In his own doctoral study which was an observational study of seven CHEMStudy teachers, Ramsey (83) developed a coding system for teacher intent, actual classroom, communication, and participant roles. As a result, he identified common patterns reflecting a 'deductive teacher-oriented approach to teaching content'.

Other studies relating specifically to CHEMStudy included those of Hardy, Atwood and Johnson. Hardy (84) found that regardless of levels of mental ability, 104 students enrolled in CHEMStudy classes in Texas high schools achieved better on a standardized ACS High School Chemistry Examination than did a comparable 'traditional chemistry' group, but that there was no significant difference on the Watson-Glaser Criticial Thinking Appraisal. In the study by Atwood (85) of cognitive preferences, students of CHEMStudy showed a preference for 'fundamental principles' over 'memory of facts', and there was a negative correlation (-0.27) between cognitive preference scores and CHEMStudy achievement scores for students preferring 'memory of facts'.

Fifty students in one school participated in a study designed to compare outcomes from a two-year integrated physics and chemistry course with those from separate one-year sequences of CHEMStudy and PSSC physics. The integrated course was found more effective in teaching concepts of atomic structure and chemical bonding, in developing positive attitudes and improving retention of chemical knowledge at the end of the two-year programme; and was equally effective in developing understandings of science and scientists.(86)

A study by Tamir (87) in Israel showed that a modified form of CHEMStudy was less effective than a form of BSCS (Biological Sciences Curriculum Study) biology in improving student understanding of the processes of science.

In a succinct overview of science curriculum evaluation studies, Welch (88) summarized many advances made in instruments and methodology, and cited examples of representative studies, especially for the American curriculum projects. Few of those reported, however, related to chemistry education. An exception described by Welch was a study involving a chemistry cognitive preference test developed by Marks.(89) This test tapped student preference for reasoning based upon memory, practical application, critical questioning or fundamental principles. Marks found that CBA students scored higher on the latter two scales, and traditional students scored higher on the memory scale.

Another earlier study based upon CBA chemistry was concerned with its longer-term effects. Matched on the basis of mental ability and high school attended, two groups, each of 30 university chemistry students who had respectively studied CBA and non-CBA chemistry at high school, were compared on university performance, continuation of science studies and self-reports of laboratory techniques. Within the reservations of the sample size and validity of testing procedures used, CBA students achieved higher university grades, continued science studies longer, and rated themselves higher on laboratory techniques.(90)

Still other studies sought to make comparisons between CHEMStudy, CBA, and conventional chemistry. Two such summative evaluations are those of Troxel, and of Schaff and Westmeyer. Controlling his sample for teacher qualifications in chemistry and in-service education or experience, and size of school, Troxel (91) in his study, randomly enrolled 1,333 students at three grade levels (10, 11, 12) into groups learning chemistry by CHEMStudy, CBA and from a popular textbook (*Modern Chemistry*). The students were taught be 23 teachers in Illinois and Iowa. He used as criterion tests the ACS standardized General Chemistry Examination (testing recall and application), the TOUS (testing understanding of science and scientists), the Watson-Glaser Critical Thinking Appraisal, and the Prouse Survey (presumably assessing attitudes towards the school subjects of science and chemistry). Overall results indicated that CBA and CHEMStudy students had superior results in their knowlege and ability to apply chemistry, in their understanding of science and scientists, and in critical thinking ability. Some CBA students (grade 11 level) developed a lower preference for science.

A specially-designed test was developed by Schaff and Westmeyer (92) to explore differences purportedly generated by studies of 'modern curricula'(CBA and CHEMStudy) and conventional curricula (as represented by two popular American chemistry textbooks). The test comprised two parts, the first based upon knowledge of chemistry, and the second based upon 'evaluation', in the sense that Bloom (93) designated it in his *Taxonomy of Educational Objectives* as the highest level of cognitive thinking. Students were asked in this second part of the test to evaluate given situations in terms of a hypothetical model of gaseous behaviour. The performance of the modern curriculum group of 12 Illinois classes on evaluation was superior to that of the conventional 12 classes, but there was no significant difference in performance on the knowledge component of the test.

A more generalized type of finding from summative evaluation was that, although the nature of instructional materials and teacher education had shifted towards the discipline of chemistry, the intended stimulation of increased interest in chemistry and chemical careers had not taken place.(94)

The usefulness of summative evaluation as a precursor to curriculum redevelopment is illustrated through the high-school (college-preparatory) chemistry course at Marple Newtown Senior High School. Students were provided with statements of 168 behavioural objectives and their achievements evaluated. Objectives which were not regarded as significant or prerequisite to subsequent objectives were then eliminated, and a new course was developed based upon 86 objectives. Significant increases in student achievement resulted. Further improvements in achievement were effected through individualization of learning rates.(95)

At university level, there are very few reported attempts at summative evaluation. Doubtless, the growth of student evaluation of tertiary teaching (most of which occurs within the institution and is not subsequently published) partly serves the purposes of summative evaluation. Two published tertiary level reports relate to PSNS and to an individualized chemistry programme.

The evaluation of the PSNS course was based upon determining whether PSNS achieved its specified objectives, and if so, whether it achieved them more effectively than other alternative courses achieved those same objectives. Twelve university professors from 10 United States colleges in eight states who were simultaneously teaching both PSNS and a conventional physical science course were involved. Their 1,000 students were randomly assigned to experimental (PSNS) and control groups.

The students undertook pre- and post-testing on tests related to two main objectives of PSNS, namely, to improve student attitudes towards science and to improve their understanding of the scientists' processes. Student attitudes were evaluated on a number of dimensions using the semantic differential technique (e.g. boring → fun), and their interest in school subjects was assessed on the 'Academic Interest Measure'. Additionally, the 'Scientific Attitude Inventory' was administered. Process understanding was evaluated using a combination of selected items from two pre-existing tests (Test of Understanding Science and Science Process Inventory).(96, 97)

The key results of the evaluation of PSNS show that 'PSNS students had more positive attitudes and interest in science upon completion of the course than did students in other physical science courses', and that 'differences between the courses on measures of science process understanding were not statistically significant.'(98)

Evaluated both in terms of cost-effectiveness and learning effectiveness, an integrated audiovisual and computer-assisted individualized first-year university chemistry programme was found more effective than the traditional programme. Using the same examinations, first-class grades increased from 18 per cent to 50 per cent, the mean score was raised from 55 per cent to 66 per cent, and failures reduced from 17 per cent to 9 per cent.(99)

The dearth of educationally significant evaluation studies must be a cause of great concern. How do we know that efforts to improve chemistry curricula - both pre-university and university - are at all effective? Do we need to reconsider chemistry education objectives? Answers to such questions demand carefully designed action research studies. The bulk of reported studies relates to two American secondary school curricula, CHEMStudy and the CBA project. Yet, even in relation to the major objectives of these curricula - of having students in classrooms replicating the research methods of the chemist - one must lament that educational evaluation remains in too primitive a state to have developed sensitive, usable and valid techniques for detecting whether these objectives are being met. Few chemistry curriculum evaluation studies venture beyond the traditional, conservative pencil-and-paper instruments and methods. It is inconceivable for a scientific profession to continue to tolerate such a data-free and evidence-lacking situation. Major efforts must be urgently devoted to improving chemistry curriculum evaluation instruments and procedures.

CONCLUSIONS

There is a tremendous lack of empirical data and documentation concerning curriculum development processes in general. In chemistry, literature on the subject is isolated and reports are unsystematic. Studies and literature concerning the effects of various types of curriculum development processes upon the nature of the resultant curriculum products could be most helpful in a number of ways. A new range of variables and a corresponding new field of terminology may need to be developed to support such studies.

In the absence of existing data about the processes of curriculum development, Weiss and Edwards (100) have suggested the construction of a new data bank, using the following steps:

1. Determine the decision-making components in curriculum development.
2. Determine the important dimensions on which decisions are made, through expert opinion, literature analyses, category systems, and project reports.

Relating these two proposals to chemistry curricula, one might ask what processes, for example, assist in streamlining the work of personnel involved in curriculum development or in facilitating the work of teachers and professors who have the task of implementation? Those responsible for developing chemistry curricula could help substantially by keeping detailed, accurate records of their decision-making processes:

- Who was involved?
- What influences were exerted by whom, and upon what issues?
- What criteria (if any) were used in reaching decisions, and for which curriculum components?

Some other types of research question include:

- Does the pre-specification of objectives make the processes of development and/or organization of learning experiences and/or of evaluation procedures more efficient or effective?
- Does the use of curriculum teams of personnel promote the use of a wider range of valid decision criteria?
- What ranges of differences occur internationally in the processes of chemistry curriculum development? What influences do these differences exert? What key differences (if any) do and/or should characterize the processes of chemistry curriculum development at pre-university and university levels?

A significant initiating action would be for the Unesco field chemistry experts to develop such reports, and for Unesco to publish details of the reports.

Finally, in a recent review of research concerning the forces which influence curricula, McNeil (101) commented that there was little evidence to suggest that knowledge about the process of curriculum development was significantly shaping school curricula. If that was true for curricula in general at secondary school level, it is even truer concerning chemistry curricula, and unfortunately it is a major understatement of the situation for university level chemistry curricula. Let us hope that we are about to witness a decade of change in our understanding and application of curriculum development processes paralelling in intensity the efforts of American secondary school curriculum development projects.

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Improved techniques of assessing student achievement

by T. Askounes Ashford

INTRODUCTION

In recent years major efforts have been made in many parts of the world to improve chemical instruction. New programmes for the training of teachers have been instituted and seminars, workshops, and review sessions have been schedules for the upgrading of in-service teachers. New and modernized textbooks and laboratory manuals have been written and state-wide or nation-wide committees have been at work modernizing the courses of study. Laboratories and demonstration facilities have been improved. Yet there is a serious risk that all these efforts will fall short of their goals, unless there is a corresponding improvement in the quality of examinations and in the methods of assessment.

Examinations exert a powerful influence on the curriculum. The reason for this is not far to seek. Assessment is not merely a part of teaching; it is central to teaching.(5, 6) It is an activity that goes most quickly and most directly to the heart of teaching. It is by means of examinations that teachers evaluate the student and determine not only his day-to-day success or failure but ultimately, perhaps, his station in life and his entire future. In preparing an examination the teacher implicitly declares that the questions he asks of the student represent the essential part of the subject matter. The examination questions represent the goal towards which all teaching is directed, the crystallization of what the teacher considers important. Therefore, when the teacher considers what is important to test he is really considering what is important to teach.

Examinations exert a powerful psychological influence on the student. During an examination session the student is faced with a challenge, to do the best he can since he wishes to succeed and also knows that the results will effect his immediate status and in some undefined way his future. He has been studying, learning, and preparing for this encounter and therefore does his very best.

The greatest influence is exerted by the comprehensive examinations, given at the end of a school term or for certifying purposes such as entrance to higher institutions,awards or scholarships or certification for employment. The content and level of the examination provide a feedback on the teaching which has been used in the curriculum. The power is also felt in another way. The entire life of the examinee may be determined by one examination.

Comprehensive examinations if given as finals, especially if prepared or given by an outside agency, exert a powerful influence by feedback. If given for selection purposes they affect the institutions or agencies that give them. The quality of the examination determines whether the institutions or agencies are selecting the most competent of the contestants.

The influence of examinations is reciprocal. In a study by Osborn (54) it was found that the introduction in the United States of the new curricula entitled the Chemical Bond Approach or CBA (12) and Chemical Education Materials Study or CHEMStudy (13) has influenced the content of the Graduate Record Examination, increasing the number of questions which test principles (as against factual information) from 13 per cent in 1948 to 83 per cent in 1970.

Rogers (59) in a provocative article entitled 'Exams: powerful agents for good or evil in teaching' analyses the many ways in which examinations can be used or misused in teaching. He discusses various ways in which they may be used to advantage in the classroom, but he concludes that comprehensive examinations should be used only as 'entrance' (that is, placement) examinations but not as 'exit' or final examinations nor for determining the final grades in a course. However, what is an exit examination for one course may be an entrance examination in a succeeding course.

Matthews (47, 48) recognizes the great interest generated recently by the introduction of objective examinations in Europe and recommends the new techniques. However, he adds the following warnings: (a) There is a need to increase and coordinate training in the new techniques; (b) We must face the fact that in modern examining, with limited resources, the quality of examinations will be inversely proportional to their quantity; (c) We seem to have forgotten that examinations can be used to evaluate curricula as well as candidates; (d) There is a danger in thinking that our examinations, after the present reform, will assess all the important qualities of candidates.

Recently the question of accountability in education has been prominent. Gomel (30) discusses the various functions of examinations and suggests that they may be used in accounting for the outcomes of our educational system.

An international workshop held in Ceylon in August 1968, is reported by Halliwell.(34) During the workshop the entire process of evaluation was discussed and reported, including the following: aims and objectives of education in chemistry; the forms of examinations; planning an examination scheme; administration and execution of an examination programme, and the uses of examinations in curriculum reform.

For further reference the author recommends Educational Measurement, a comprehensive treatise on evaluation, edited by R. L. Thorndike; (75) Testing and Evaluation for the Sciences by W. D. Hedges;(36) and an article by C. H. Nelson in the Handbook on Formative and Summative Evaluation of Student Learning.(50)

ARE WE TESTING THE SIGNIFICANT OUTCOMES OF CHEMICAL EDUCATION ?

A major issue that can be detected running through the recent literature is concern whether our assessment methods measure the significant outcomes of chemical instruction. For the purposes of this paper two major areas may be identified: 1. Concern with respect to the form of the examination, and 2. Concern with respect to the content of the examination.

Forms of items

Essay v. objective examinations

The controversy between the essay and the objective form of examination began with the introduction of the objective tests in the United States more than half a century ago and is still continuing. It would seem that by now all the virtues and vices of each form have been stated repeatedly and exhaustively and nothing new can be added. Nevertheless, the controversy is still alive although the stage has shifted from the United States to other parts of the world.(27, 32, 53)

In the United States the controversy has subsided. The merits of each form have been recognized and one finds both forms used side by side. The essay is typically used under the rather intimate conditions of a small class, where the time for preparation of an objective test is limited and the reading of the essay test is not too demanding on the teacher's time. There is a kind of naturalness in assigning an essay question, and the teacher gets the feeling that there is a direct communication between him and the student. In contrast, the message from the student to the teacher in the form of marks in an objective test appears too impersonal. It is only fair, however, to state that the values of the objective tests have been demonstrated and recognized and as a result these tests are widely accepted. Objective tests are used far more widely than essay tests. This is especially true when large numbers of students are involved, as in comprehensive or final examinations. In all state-wide or national testing one finds the almost exclusive use of objective examinations usually of the multiple choice variety.(5, 6)

In Britain and the Commonwealth countries the introduction of the objective test is relatively new and one finds considerable controversy.(27, 32, 53, 73) One may expect a controversy to arise in other countries, as they face the problem of replacing some or all of the essay examinations with objective examinations.(41)

In a review article Thompson (73) analyses the use of multiple-choice and essay examinations in Australia. It appears that objective examinations are used widely in that country.

The essay examination

Of the many advantages and disadvantages ascribed to essay examinations, the following appear to be the most important.(53)

Advantages

1. The essay question is direct. The questions appear natural and a continuation of the teaching situation.
2. The student has the opportunity to give a direct answer to a direct question and to express it in his own words.
3. Student application is tested in the sense that the student responds to a new situation.

4. The teacher has the feeling that there is a direct communication between him and the student.
5. If the answer is wrong, the teacher may detect the source of the difficulty and correct his subsequent teaching.

Disadvantages

1. Essay questions are often vague and ambiguous.
2. An essay examination is at best an inadequate sample of an entire course, since only a few questions can be asked in a given session.
3. The depth and scope are not evident in the questions upon inspection of the examination. Typically the method of scoring and the level expected are not indicated. For example, the same question may be asked of a beginning chemistry student at secondary level or in a Ph.D., examination. There is no indication in the question of the level at which the response is expected, nor how it will be graded.
4. The scoring of essay questions is notoriously unreliable and depends on the reader; his competence, training, background, standards, the time at his disposal, his philosophy, temperament, and even mood at time of reading.

The multiple choice examination

Taking the multiple choice examination as the best objective examination the following appear to summarize the advantages and disadvantages: (53)

Advantages

1. Multiple choice examinations quickly test a wide range of subject matter.
2. They widely sample the field.
3. With care, all 'higher' mental processes in the cognitive domain can be tested.
4. Such examinations can be used for large classes.
5. They can be scored reliably.
6. The content, scope and level of the examinations is explicitly evident.
7. They can be pre-tested.
8. They are subject to statistical treatment and analysis as to content, reliability, validity, and their usefulness in a given situation.
9. They can be used for comparisons of classes, courses of study, curricula, or entire school systems.

Disadvantages

1. They are impersonal.
2. It is difficult to assess application of knowledge.
3. There is no evidence as to how a wrong answer was deduced by the student.
4. Logical development of an argument cannot be tested.
5. They test only retention of subject matter and may fail to test the 'higher' mental processes.
6. They test recognition rather than recall. The student may respond passively.

Other forms of assessment

The limitations of paper and pencil tests have been recognized. Walkley (78) discusses the drawbacks of both essay-type and objective-type examinations based on a survey of the attitudes of physical chemistry professors to examination marks. Alternate methods of assessment are briefly discussed. He proposes that in addition to validity and reliability, a third variable, 'efficiency' be recognized. Chmielewski (15) discusses the criteria for the evaluation of education attainment in chemistry. Kalra (43) proposes a new evaluation approach in chemistry for non-science majors. The procedure would recognize the different degrees of background and science proficiency. Eiss and Harbeck (22) treat at length the field of behavioural objectives in the affective domain.

Among alternate methods of assessment are the following:

1. Practical examinations involving the laboratory. Instruction in the laboratory has been universally considered as an essential part of chemistry teaching. Traditionally, evaluation of the student takes place as a continuous assessment through observation by the teacher. The type of evaluation varies from course to course and from level to level. In an elementary course evaluation centres on general behaviour such as neatness, ability to set up and use the apparatus, as well as understanding the purpose of the experiment, the course of the experiment and the interpretation of the results. In most advanced courses evaluation is centred on the quality of the results obtained by the student. For example, in qualitative analysis, the evaluator may look for ability to detect, or failure to detect, an 'unknown' in usual amounts, or in traces, or in the presence of interfering substances; in quantitative analysis he may look for the accuracy of the determination; in organic preparations he may look for yield and purity of the prepared substance.

Practical examinations for continuous assessment are widely used in the secondary schools of Europe,(71, 72) in the Soviet Union,(34) Poland, Spain, India and the United States, and probably in all parts of the world.

Many attempts, especially in elementary courses, have been made to include assessment of laboratory skills in the final examination. In his study for the Council of Europe,(71, 72) Thompson reports that a practical part is included in the final in four out of 15 countries. Gardner and Hearle (28) prepared an examination for laboratory skills for a pilot study in 1972-73. The author has not found a widely used instrument assessing laboratory performance as a part of a comprehensive examination.

2. Oral examinations. The oral examination has long been accepted as a normal element in student assessment. This form of assessment has not yet yielded to critical analysis. Oral examinations vary widely with respect to such characteristics as length, form, procedure, purpose, level, effectiveness, reliability, as well as the philosophy and competence of the examiners. Yet oral examinations are widely used in Europe,(71, 72) in the Soviet Union,(34) in Ceylon,(34) and presumably in all parts of the world. In the United States they are limited almost entirely to graduate level for the granting of master's or doctoral degrees. Because of its wide use, this form of examination deserves a comprehensive study.

3. The long essay, or term paper, is used predominantly in special courses.

4. Open book examinations are used widely. (10) An important feature is that they deemphasize rote memorization and emphasize ability to use the information.

5. Take-home examinations are used in many parts of the United States. The assignment varies with the instructor. They also emphasize the ability to use actively knowledge and skills gained in the classroom, as well as those derived from texts and the library.

Content of the examination

More important than the question of what form is to be used (that is, essay or objective) is the consideration of what is to be examined.

In the essay form, the question of the adequacy or appropriateness of an examination does not come up explicitly. It is assumed to be taken care of by the nature and quality of the questions, by the extent of sampling which the test as a whole accomplishes and by the capacity of the reader to look for responses beyond the mere return of information. Upon inspection alone, an essay examination can only be evaluated by analysing it in terms of the quality of the questions, the depth at which the questions are asked, the breadth of sampling of the field, and the overall 'tone' or 'level' demanded. However, unless one knows how the examination is to be scored, one cannot know what constitutes a satisfactory answer or a passing score, nor have any confidence that the significant outcomes of instruction have been met by a student passing the examination. All these matters are either in the mind of the examiner or are decided during or after scoring upon inspection of the scores.

In contrast, before it is given, the objective examination lends itself to analysis with respect to the content, breadth of coverage and depth of understanding, as well as method of scoring. All these elements are evident on the examination copy. Moreover, their analysis can lead to further development in theory, practice and technique, so that the examination can assess all the significant outcomes of instruction, and each of them to an appropriate degree.

With respect to content, at least two dimensions have been recognized.(4) The first, and most obvious, is the subject matter content. The very nature of the objective test requires the examiner first to state explicitly the subject matter of the course or field to be examined. He must make an outline of the course and list the important terms, principles, concepts, theories and so on which are contained in it and which he presumably wants to sample. This has led to the development of a careful analysis of courses of study and a listing of what have been called subject matter objectives. A detailed and carefully constructed course-of-study makes it possible to construct test items and to assemble a test which is an adequate and fair sampling of the course. The subject matter content is the most obvious dimension and was aimed at very early.

However, it has also been recognized that there are other dimensions in addition to subject matter. It is clear that the entire subject matter of a field can be sampled by questions of terminology alone, or factual information alone, but it is also clear that these would not represent a fair sample of what is expected of the course. The subject matter of chemistry contains not only information and vocabulary but also principles which must be understood, applied and distinguished from observable facts, and so on. In other words, it has become clear that dimensions other than subject matter are an integral part of the course and are also to be measured.

One of the first distinctions commonly made is between memory and reasoning.(6, 42) This dichotomy has been expanded naturally into a continuum of levels of attainment. One such version was developed by Ashford and is being used by the Examinations Committee of the ACS. (1, 4) To facilitate the analysis and to insure fair sampling of all the subject matter and all the levels of attainment a grid was developed, which appears on Table 1.

More recently it has become customary to speak of objectives. Thus one speaks of subject matter objectives and of behaviour objectives. The most widely known classification for the behaviour objectives is the Bloom taxonomy widely used throughout the world.(11, 23) The taxonomy classifies questions into six hierarchical levels of increasing complexity and presumably of higher development: knowledge, comprehension, application, analysis, synthesis, and evaluation. However, the Examinations Committee of the ACS finds the 'levels of attainment' of the grid in Table 1 more immediately meaningful to the chemistry teachers.

A few examples of items may be given, identified with respect to level and area.

Level I, Area 5

Knowledge of important facts

Question: Which will produce a combustible gas on reaction with cold water?

Table 1. The grid

CONTENT BEHAVIOUR OBJECTIVES ↓	Area 1 Chemical change, element compound; laws of chemical combination, kinetic molecular theory, gas laws, atomic theory, chemical symbolism, formulas, equations, calculations	Area 2 Solutions, ionization acids, bases, salts, neutralization, hydrolysis, activity series, electrochemistry	Area 3 Oxidation-reduction, heats of reaction velocity, chemical equilibrium	Area 4 Atomic structure and chemical behaviour periodic system	Area 5 Chemistry of the common elements and their compounds. Physical and chemical properties of hydrogen, oxygen, halogens, sulfur, nitrogen family, typical metals
I. Ability to recall important information Knowledge of important facts Knowledge of definition of important terms Acquaintance with important concepts Verbal understanding of theories and principles General knowledge of the physical and chemical properties of the more important elements and their compounds					
II. Ability to apply principles in making simple predictions Functional understanding of principles and theories of chemistry and their interrelationships Application of a definition Application of principles in situations similar to those encountered in a typical course Application of principles in new situations taken from everyday life Interpretation of a set of data and drawing conclusions from them					
III. Ability to apply principles quantitatively by carrying out calculations Quantitative meaning of chemical symbolism Balancing chemical equations					
IV. Ability to use the scientific method. Includes the following aspects of the method: Distinction between observed phenomena and their theoretical explanation Explaining phenomena in terms of theory Giving the experimental evidence for a theory Factors to be controlled in an experiment Statements which are true merely by definition					

1. Hydrogen chloride
2. Sodium oxide
3. Ethane
4. Calcium
5. Calcium carbonate

Level I, Area 4
Verbal understanding of principles and theories

Question: Which equals the number of electrons found in the orbits of a neutral atom?

1. The number of neutrons
2. The atomic weight
3. The number of protons subtracted from the atomic weight
4. The number of electrons in the nucleus
5. The atomic number

Level II, Area 3
Application of principles in situations similar to those encountered in a typical course

Question: The following system is in equilibrium at a high temperature

$3H_2 + N_2 \rightleftharpoons 2NH_3$ + heat

(All substances are gases.) What will be the result if the pressure on the system is increased?

1. The amount of H_2 and N_2 will increase
2. The amount of NH_3 will increase
3. The amount of all three substances will increase
4. The reaction will go to completion to the right
5. No change will take place

Level II, Area 3
Application of principles in new situations taken from everyday life

Question: Although a heap of grain will burn very slowly, flour dust suspended in the air in a room may explode if ignited. Which best explains this difference?

1. Small particles give more energy than large particles on reacting
2. Small particles offer a greater surface of contact with air
3. Greater circulation of air about the smaller particles distributes the heat more evenly
4. Small particles burn more completely than large particles
5. The heat of reaction of small particles is greater

Level III, Area 1
Calculation involving molecular and atomic weights

Question: Which expression gives the mass of a litre of chlorine, Cl_2, at standard conditions? The atomic mass of chlorine is 35.5.

1. $\frac{35.5}{22.4}$
2. $\frac{71.0}{22.4}$
3. 35.5×22.4
4. 71×22.4
5. $\frac{71 \times 22.4}{760 \times 273}$

Level IV, Area 2
The relation between theory and experiment - experimental evidence for a theory and the explanation of phenomena in terms of theory

Question 1: Which statement is the best experimental evidence that sodium chloride is a strong electrolyte?

1. Sodium chloride is very soluble in water
2. Sodium chloride solution is a good conductor of electricity
3. A sodium chloride solution freezes below 0°C.
4. Sodium chloride is formed by electron transfer
5. Sodium chloride molecule contains free electrons

Question 2: Now, which statement above is the best theoretical explanation that sodium chloride is a strong electrolyte?

1. Statement 1
2. Statement 2
3. Statement 3
4. Statement 4
5. Statement 5

Level IV, Area 3
Determining whether a statement is true because it is a statement of observation, true in the sense that it is a consequence of an accepted theory, or true simply by definition

Question: The boiling point of water at standard pressure is 100°C. How would you characterize this statement?

1. It is based on observation using pure water, an accurate barometer and an accurate thermometer.
2. It is a consequence of the definition of the absolute temperature scale
3. It is true by definition of the Centigrade temperature scale
4. It is true by definition of standard pressure
5. It is a logical consequence of the kinetic molecular theory

Level IV, Area 2
Factors which should be controlled in an experiment

Question: It is desired to study the effect of temperature on the rate at which sodium chloride dissolves in water. A series of determinations are performed. The procedure is to add an excess of salt to a limited amount of water and after stirring for some time to evaporate a small sample and weigh the residue. Which should be kept constant during any one determination?

1. The extent to which sodium chloride dissolves
2. The solubility of sodium chloride in water
3. The temperature of the water
4. The average size of the crystals of sodium chloride
5. The amount of solid left undissolved

Additional items may be found in reference 4 identified as to level and area, and many more items may be found in any ACS test,(1) although they are not identified as such.

The grid is extremely useful in the construction of the test. A scatter diagram of the items, identified with respect to level and area, helps determine that a test contains at least one sample of all levels and all areas.

Using the Bloom taxonomy, Hudson (38) describes how to devise an objective test by drawing up a detailed specification of the abilities and areas of knowledge that are to be tested and by using pre-tested objective questions. With these tests it should be possible to measure a student's attainment more accurately and more reliably. Similarly, Demchick (19) prepared a sample test in chemistry, giving examples of all six levels of cognitive abilities of the Bloom taxonomy. Even (23) attempted to relate teacher-assigned grades to taxonomy type objectives.

CONTINUOUS ASSESSMENT V. ONE-TIME COMPREHENSIVE EXAMINATIONS

Two rather distinct systems are used in different parts of the world. One extreme is the continuous assessment of student performance by the teacher using oral recitation, short essay questions, short objective questions, periodic quizzes and observations of behaviour in the laboratory. In continuous assessment we may also include the various forms of self-paced instruction, although the tests are used by the student for study purposes rather than by the instructor for evaluation purposes. The other extreme is a one-time comprehensive examination given by an outside agency, which has the ultimate responsibility for evaluating the student. In the latter category must be placed entrance examinations to institutions of advanced learning, and the certifying examinations given in connexion with selection for scholarship awards or for employment. All variations between these two extremes are practised in the various parts of the world.

Continuous assessment

In the United States (49, 83) evaluation is largely under the undisputed control of the teacher during the term, usually a semester or a year, in which the student is in his class. In general, assessment begins by assigning a broad topic, using a chapter or series of chapters in a text. The assignment may include additional work in the library as well as projects. Then follows a period of class meetings during which the teacher presents the material by expanding, explaining, summarizing and sometimes demonstrating various aspects of the subject matter. Typically questions are asked during class recitation and the teacher makes a mental (sometimes written) note of the responses of the student and these become a part of the assessment of the student. At the end of the period, which may last several days or weeks, a brief test called a quiz is given. Longer quizzes are given periodically and a final examination is given at the end. The results of all the testing, variously weighted according to the philosophy of the teacher or the school, form the total evaluation of the student. It is expressed on a five-point scale usually as a letter grade with the following meaning: A - excellent; B - good; C - average; D - fair or poor, but passing; F - failing.

Grades are often quantified with the following numerical point equivalencies: A - 4; B - 3; C - 2; D - 1; F - 0.

The final test is typically a comprehensive examination prepared by the individual teacher in perhaps the majority of cases. However, also widely used are standardized tests prepared by national committees such as the Examinations Committee of the ACS, the Educational Testing Service, other testing agencies, state or district committees or even committees that are only school-wide. In nearly all cases, however, the teacher uses a test of his own choice and may weight the results of the testing in any way he deems appropriate. Only in rare cases is the final examination weighted by more than 50 per cent of the total assessment for the entire course.

While it is recognized that the level of competence or achievement represented by a given grade varies from teacher to teacher and from school to school, grades are nevertheless widely used for evaluating the quality of students. They are used for entrance to colleges or for admission to specific programmes in a given institution. They are also used to determine whether the student will graduate or not. Discussion of continuous assessment has recently received considerable attention in the United Kingdom and other Commonwealth countries. Yeoman (82) reports that in the Certificate of Secondary Education (CSE) in the United Kingdom, continuous assessment as reported by course work and teacher assessment constitute typically 15 to 30 per cent of the final assessment.

The following arguments have been advanced in favour of continuous assessment.(8, 10, 81)

1. It permits the teacher to interact continuously with the student
2. It promotes learning so that continuous corrections can take place
3. It is psychologically sound, in that learning takes place gradually, and after repeated exposure
4. It gives the teacher a greater opportunity to form opinions about personal characteristics, such as reliability, promptness, motivation, willingness to work hard, etc.
5. It gives the teacher a continuous feedback so that he can alter and improve his teaching

In continuous assessment the major problem is the training of classroom teachers in the art and science of examination construction.

The comprehensive examination

The arguments for the comprehensive one-time examination are many and include the following: (29, 80)

1. It measures the final outcome of instruction. It is of no significance whether the student knew or did not know a particular item at some time early in the course.
2. All students are measured against each other at one time
3. It permits the adequate sampling of large blocks of subject matter
4. It permits the testing of interrelations between various parts of a field rather than 'bits and pieces'
5. It is usually prepared with more effort, and presumably with greater competence.
6. It can be analysed statistically and yield information with respect to students, curricula, courses of study, schools and school systems, as well as provide comparisons

INTERNAL V. EXTERNAL CONTROL

Practices in various parts of the world

The question whether the examinations should be controlled internally or externally is one of the thorniest and most complex problems. The actual practices vary considerably from country to country and depend a great deal on the history of the educational system, on its philosophy, type of government and social conditions, as well as on the purposes for which the examination is given.

In the United States the control is almost universally internal. The examination is nearly always under the control of the classroom teacher. Even when a standardized examination is used, the choice as to whether an examination is to be given and the decision as to what value will be placed on the results are the prerogatives of the classroom teacher.

In the European secondary schools practices vary. External control is prominent in England and Wales, in France and in the Netherlands; on the other hand internal control is practised in the Federal Republic of Germany, Switzerland, and Belgium.(71)

In the United Kingdom, as in many Commonwealth countries, notably India, external control has been the tradition. However, in these countries there is a trend towards giving the teacher the whole or at least a part of the authority. For example, in Ontario, Canada, the control is now wholly internal. Similarly, in Spain internal control is coming more and more into use since the recent Educational Law giving autonomy to the universities.(3) External control seems also to be practised in the Soviet Union,(29) Japan,(35) Egypt,(16) and Kuwait. In Poland control is almost exclusively internal.

It would be desirable to make a comprehensive study of the practices throughout the world.

The International Baccalaureate Office, with headquarters in Geneva, provides materials for common programmes in international or multinational schools in about 15 countries. These materials include an examination which is used for awarding a diploma and for admission to universities in several countries. The examination consists of a written, an oral and a practical part. The written is common and in a sense represents external control. However, the practical and the oral are conducted by the school with an overall evaluation of the level in that school (moderation) by the visiting examiners.(70)

Internal control

The following arguments have been advanced in favour of internal control:

1. It places the responsibility of assessment on the person or persons who have immediate contact with and knowledge of the students
2. Knowing the student, the teacher is in a better position to interpret his responses
3. It permits the assessment not only of the tangible objective and crystallized outcomes of instruction but also the 'intangible' outcomes including personality characteristics, motivation, outlook, depth of understanding, ability to plan a course of action, and the like. The intangible outcomes may be more important than the tangible
4. It permits experimentation on the part of the teacher, school or school system without fear of failure or a record damaging to the student or to the school
5. It permits freedom to change, and avoids the danger of regimentation from a central source or of resistance to innovation
6. It leaves the educational process to local control with the concomitant possibility of making the curriculum more meaningful and relevant to students in the local situation

External control

The following arguments have been advanced in favour of external control:

1. Uniform standards can be applied to the entire population
2. The examination can be written by competent specialists and hence possesses higher reliability and validity
3. The examination can be a powerful means for updating the entire process of instruction, especially in a developing system where teaching personnel, courses of study, methods, textual materials and physical equipment need upgrading

Who should prepare the comprehensive examination?

As regards the problem of who controls the examination, an essential but distinct question is who prepares the examination? Two methods are widely used with considerable variation:

1. The examination is prepared by a teacher or a group of teachers in the field. Frequently expert advice by test specialists and statisticians is available;
2. The examinations are prepared by a professional examiner or a group of examiners. Typically, teachers of the subject are used as consultants with considerable variation in the amount of input by these consultants.

The first method is used within a given school or a relatively small school system. It is also widely used in graduate schools for admission of graduate students, preliminary examinations for advanced degrees or for the granting of advanced degrees.

The second method is almost universally used in the United States by such testing agencies as the Educational Testing Service and the Graduate Record Examination, as well as by the various professional associations such as the American Medical Association or the American Dental Association. It is likewise used by governmental agencies, national and state, for hiring personnel and for certifying professionals and by many similar agencies, throughout the world.

Among the large testing organizations, the Examinations Committee of the American Chemical Society is rather an exception.(5) The examination in each field of chemistry is prepared by teachers in that field. It is a fundamental principle of this Committee that only outstanding teachers in the field can write a valid, properly balanced examination testing the significant outcomes of instruction. The main Committee itself offers to the subcommittee in the field whatever is necessary with respect to question writing and statistical treatment.

USES OF THE TESTS

A considerable amount of recent literature is devoted to the various uses of tests. The following uses are representative.

Uses in the classroom

In a doctoral thesis, Cummings (17) presents and discusses a rather exhaustive list of situations in which tests serve as learning tools and as means of involving students.

Okey, Brown and Fiel (51) use the tests for diagnostic evaluation of individualized instruction. De Rose (21) uses the tests for evaluating learning in individualized self-paced science courses.

Hoare and Revans (37) find that certain questions can be used quantitatively to separate students' ability to assimilate chemical knowledge from their ability to apply that knowledge in unfamiliar situations and thus distinguish 'blotting paper' from 'thinkers'.

Marso,(46) in a study of test difficulty and student achievement, found support for the classroom educators' contention that unit examination difficulty is related to student effort and achievement. Theoretically, it would seem that unit examinations need to be difficult enough to motivate students to study and obtain a suitable level of test reliability and yet not so difficult as to result in inadequate reinforcement to maintain study efforts. Just what level of unit test difficult is consonant with these goals was not revealed by Marso's data, but they do suggest that unit test difficulty level influences student achievement as well as test reliability. It was suggested that the relationship between test difficulty and study efforts and achievement be further investigated. If this relationship does exist at all grade levels and for various testing approaches, it may have a profound effect upon student motivation over a period of years.

In an innovative project Lunde and Jones (45) had the students participate in writing the examination by submitting questions. Among the advantages they found were the following:

1. The students will think the test is fair
2. It is real to the students and it encourages them to learn the material by discussing it with each other
3. From the presence or absence of questions the teacher can evaluate how well he has covered the material
4. Wrong answers will reveal misunderstandings before the end of the unit
5. The student becomes more personally involved in the course

The literature abounds in numerous other uses of tests in the classroom. Andersen (2) uses examinations for developing favourable attitudes toward science. This he does by making the examination easier so that the student acquires a feeling of mastery and accomplishment. By basing questions on the student's viewpoint, motivation is also increased. Liszka (44) gives tests to keep students alert, while the results serve as a warning signal to the teacher when help is needed. Ivanova (39) utilizes a system of short written tests followed by analysis of each test. Sautkina (60) utilizes frontal conversation and, rarely, individual oral questions. Piosik (56) uses the short-answer type, applicable to general chemistry, analytical chemistry or to historical aspects of chemistry. Gorbatov (31) employs flip-over cards which the student uses in responding to short-answer questions. De Rose (21) uses essay-type tests at the end of assignments for self-paced study.

Uses in placement and prediction

Comprehensive tests have been widely used for assessing the background of students for college entrance,(74) for the placement of students at the proper level in college, as well as for granting college credit. The tests have been used to predict performance in subsequent courses. The following are typical studies.

Denny (16) used a test entitled Mathematics Skill Test (MAST) to determine the mathematical preparation of students entering a high school chemistry course. The test was prepared and validated by the author. He found the test reliable and valid and suitable for use by chemistry personnel to determine individual student preparedness, prior to the student's encountering chemistry difficulties.

Sieveking and Larson (65) use the High School Chemistry Examination Form 1963 (ACS-NSTA), the Scholastic Aptitude Test in Mathematics (SAT-Math), the high school grade point average and a factor assigned to the school of registration (engineering or arts and science) to predict performance in a college freshman chemistry course. They derived the following regression equation for the prediction:

Predicted grade standard score = .39 (ACS total) + .30 (high school average) + .13 (SAT-Math) + .11 (school of registration)

Haffner (33) used the High School Chemistry Examination Form 1963 for placement of students in the proper section of a chemistry course in the United States Air Force Academy and for awarding validation credit. He concluded that the Predicted Chemistry Grade (PCG), as used at the Air Force Academy, is a valid and useful tool for placing cadets into freshman chemistry courses which vary in degree of difficulty and acceleration. The PCG has proved to be the best single predictor of a cadet's performance in General Chemistry. The ACS Cooperative Exam score is an important component of the PCG, and in addition, ACS scores are used to award validation credit in chemistry.

A procedure whereby students placed in an accelerated course can transfer to a lower level course without losing step with their contemporaries is not only desirable but essential, since placement in advanced or accelerated courses is not 100 per cent accurate.

Fackler (24) discusses the advanced placement programme used in the United States granting college credit to students who have taken advanced placement in the high school. Placement is validated by means of a multiple choice Advanced Placement test. He concludes as follows: 'If Advanced Placement courses in chemistry become recognized as sound second level courses and not courses designed to mimic the high-powered college courses, programmes in college chemistry could be strengthened accordingly. Advanced Placement credit can be granted for similar college material at schools where such material is part of the school's offering in chemistry. However, Advanced Placement teachers must not assume that their Advanced Placement course will universally substitute for a freshman chemistry course particularly for a science major. If the Advanced Placement student is properly motivated and is interested in pursuing a career in science or engineering, he should be encouraged to enroll in a good science major chemistry freshman course if one exists. He should be discouraged from seeking to enter sophomore (second-year) courses directly. With the additional year of sophistication and training, his chances for success are substantially higher than those of the average student. As a sophomore he will compete confidently with fellow students who have had the same freshman course.... A period of adjustment to the college approach appears necessary.' As one respondent stated, 'Might be just a matter of maturity'.

There has recently been a widespread movement in the United States for granting college credit for exceptional performance in high school, or even for knowledge acquired independently of any school. The credit is given by means of a set of examinations called College Level Examination Program (CLEP), featured by the Educational Testing Service.(14) There are two sets of tests: the general education set and a set for specific college subjects including chemistry. Many colleges and universities use the ACS tests as more valid. Still others use their own tests.

Sherwin and Child (62) in the United Kingdom used the A-level examinations in chemistry, physics and mathematics to predict performance in the first-year university-level examinations in inorganic, organic and physical chemistry, in physics, and in mathematics, and calculated product moment correlation coefficients. They found that the tie-up between A-levels and first-year results is significant for all the subjects of a similar nature. They also studied the predictive value on the final award of the degree, finding that the A-level score gives an appreciable indicator but that the best predictor is performance in the first-year examinations. The study also reveals the importance of mathematical ability at A-level, but more particularly overall attainment at A-level. A similar study was conducted by Oliver and Roberts.(52)

Rather novel is the use of psychological tests as predictors. Siemonkowski and McKnight (64) use a test in 'spatial cognition' as a success prognosticator in college science courses.

Group comparison

A number of studies have used standardized, comprehensive examinations for group comparisons. The following are typical. Troxel (76) used the General Chemistry Test Form 1963 (ACS), the Test on Understanding Science, Form W (14) and the Watson-Glaser Critical Thinking Appraisal, Form Ym (Harcourt, Brace and World, Chicago, 1964) to study the relative effectiveness of CBA,(12) CHEMStudy,(13) and modern chemistry. They found that the modern chemistry, CHEMStudy and CBA courses are not meeting their objectives with the same degree of effectiveness. In general, students who use the CHEMStudy and CBA course materials develop a better understanding of chemistry, develop a better understanding of science, and develop a greater ability for critical thinking, as measured by the instruments used in this investigation. Students who are enrolled in modern chemistry and CHEMStudy develop a greater preference for science than do students enrolled in CBA, as measured by these instruments.

Schaff and Westmeyer (61) use a test constructed by the authors and entitled Assessment of Evaluation Ability in Chemistry to compare the performance of students in modern and traditional high school courses. They conclude as follows: 'This investigation disclosed that students taught the modern curricula demonstrated a higher performance on the evaluation test than students taught the conventional curricula, while concurrently demonstrating an equivalent performance on the knowledge test when measured by the instrument Assessment of Evaluation Ability in Chemistry. These results substantiate the hypothesis that there are differences in the complex intellectual process, evaluation, developed in students by the two curricula. This suggests that there may also be differences in other intellectual processes of the Taxonomy.'

Oliver and Roberts (52) used the multiple choice test to study the effectiveness of the first-year of the Nuffield chemistry course in the United Kingdom. They concluded that experience to date suggests that in general the Nuffield Stage I material is suitable for pupils in the proper ability range. The abilities tested are recall or knowledge, comprehension, and application in terms of the Bloom taxonomy. Furthermore, these abilities can be purposefully assessed by means of a suitable multiple choice examination. The work was to be extended into the second year.

Vold and Mukerjee (77) used the records of graduate students at the University of Southern California who have passed the examinations in India. They claim that these examinations are extremely satisfactory for the granting of the B.Sc., and M.Sc., degrees. They compare the performance of these graduates at the doctoral level in American universities. They conclude that Indians with an M.Sc., degree may be properly admitted for graduate work in American universities but no transfer graduate credit should be given.

Thompson (73) found that College Board Science Achievement Tests are equally appropriate in both regular and special courses in biology, chemistry and physics.

Znosko (84) made an analysis of the results of year-end exams in chemistry. The paper contains tabulation and discussion of results, typical questions and final grades.

FUTURE OF THE GRADING SYSTEM

Performance of students is evaluated throughout the world in terms of grading systems. In the United States the letter grades A, B, C, D or F are used with D as the lowest passing grade. In many countries, equivalent numerical systems are used with 10 as the perfect score and 5 as the lowest passing; or 20 as the perfect score and 10 or 12 as the lowest passing. In other countries the grading is in terms of 100 with 70 or 75 as the passing score.

Grading practices have been criticised for over 70 years but these criticisms have been accentuated during the recent wave of student unrest.(68)

Educational periodicals have been inundated (40) with articles such as Down with Grades, To Mark or Not to Mark, In Opposition to Conventional Grades,(25) The Positive Function of Grades,(26) The Grade Point Average: Snark or Boojum?(55) and Will my Johnny make the Grade? The criticism centres around the following points:(18)

1. Letter grades with associated numerical values present a deceptive appearance of objectivity and precise evaluation
2. Letter grades and grade point averages distort and debase the whole learning process
3. Letter grades and grade point averages are often put to questionable use by schools and by society

A great many papers have been written and conferences have been held in response to the criticism of grading.(7, 9, 18, 40, 58, 66, 67, 70, 79) An examination of this literature, however, leads to the conclusion that while the criticisms are recognized as valid, no viable alternative exists in the complete absence of grading.

One response to many of these criticisms has been advanced. This is the 'grade contract', a variation of which is described by Shirts.(63) The student contracts for a grade, A, B, C, or D, and, in consultation with the instructor, the precise requirements are explicitly assigned in terms of readings, reports, experiments, and examinations. The student receives a grade upon completion of the required tasks, repeating any that may not be satisfactory. Shirts tried the grade contract in his class and made the following observations:

1. Most of the students contracted for an A
2. Students worked hard
3. Students who contracted for the lesser grades assumed no responsibility for class discussions
4. Assignments became burdensome, distasteful and possibly meaningless to students
5. Most students showed indications of good learning
6. Students began to display resentment

Taylor (68) describes the grade contract and assesses opinions of students who experienced the technique. Data were secured from seniors in an educational measurement and evaluation course. Analysis of student responses to a 14-item scale showed a generally favourable opinion of the grade contract system. A further comparison of a grade contract group with a control group showed that the former viewed the grade contract method as a fairer system of assigning grades than the conventional technique.

Poppen and Thompson (57) studied the effect of grade contracts on student performance and found that this research does not substantiate the value of grade contracts over traditional approaches when used with college students. There may be undetected values or values that may be obtained with further modifications. The procedure certainly does allow movement toward individualization of instruction but seems to have no real disadvantages as a grading procedure.

A more general reaction to the criticisms has been a markedly increased use of a modified grading system, employing as grades: pass-fail, satisfactory-unsatisfactory, credit-no credit, or equivalent.

Benson,(9) on the basis of returns of a questionnaire from 240 graduate schools, found the following advantages and disadvantages in the use of the pass-fail system:

To the graduate school

Advantages

1. It is more realistic because it is impossible to grade fairly under the traditional system;

2. The student cannot raise his grade point average with research or a thesis
3. The system makes it more practical for a student to take work outside of his major field
4. The pressure on faculty is reduced

Disadvantages

1. Registrar and administrative confusion results when a second system of grading is introduced
2. The grade point average does not reflect the total work of the student
3. Courses get sloppy and instructors evaluate poorly

To the students

Advantages

1. There is less pressure on the students
2. The system does not confuse research grades with the academic grade point average

Disadvantages

1. The student may be penalized in competing for stipends
2. The student cannot be recognized for outstanding work
3. The student cannot improve his grade point average with thesis or research

The use of pass-fail has also spread to undergraduate schools. The pass-fail system is widely used in the following cases:

1. Theses and research papers
2. Unstructured courses such as research, seminars, and special topics
3. Courses which are not an integral part of a student's major field of study

Recent literature suggests that the pass-fail grading will be extended to courses that cannot be graded objectively or with confidence, and to courses that broaden a student's education without the expectation of expert competence. On the other hand, sporadic reports indicate that many places having adopted the pass-fail system are now abandoning it.

CONCLUSION

The ferment on assessment continues. The importance of examinations in the educational process has been recognized and there is every indication that active interest will continue in an effort to design better tests. Examinations are instruments of measurement, and measurement plays a role in the development of any field. Just as the clinical thermometer has contributed to the development of medicine or the analytical balance to the development of chemistry, so the improvement of tests and examinations can be expected to contribute to the development of chemistry instruction.

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Trends in the training and retraining of chemistry teachers

by A.V. Bogatski

The great discoveries in physics made at the beginning of the twentieth century marked the start of a new scientific revolution which was inevitably destined to embrace all spheres of human knowledge.(1) We are daily witnesses to completely new scales and rhythms of scientific and technical progress which far surpass those achieved by scientific development throughout the previous millenia of human civilization. (2, 3) Man is making the universe his servant. He has invaded and conquered the depths of the microscopic world. Many scientific problems which only yesterday were the subject of discussion only among small groups of scientists now excite the whole world. The trend towards extending and improving the teaching of all the natural sciences, including chemistry, is accordingly logical. Contemporary man wants to have much more complete and extensive information on these matters than did previous generations. This interest is encouraged by modern scientific achievements, by the general expansion of education in the modern world and by the enormous growth of communications, including that of the information media, which together make discussion of even the most complex scientific problems accessible to millions. A contributing factor is the great social progress now being made, with the development of the socialist system throughout the world, the collapse of colonialism and the access of millions of people to an active and creative life.

The need for more extensive and more accurate knowledge makes it essential to improve the way in which all the natural sciences, including chemistry, are taught. This, in turn, brings to the fore the problem of teacher training. Mere commonsense tells us that even the most perfect teaching system is effective only when there are people capable of actually putting it into practice. Thus the problem of improving the teaching of chemistry is part and parcel of the problem of how to improve the teaching of all the natural sciences;(4) it is also closely linked with the problem of the teachers' own personalities, their degree of training, their competence and the extent to which they can communicate.

There is a shortage of chemistry teachers throughout the world.(5) This means: (a) a purely numerical shortage of teachers; (b) a shortage of good teachers working at a contemporary level. The attention of the appropriate bodies should be drawn to the fact that one of their main tasks is to increase the number of teachers. This is particularly true of developing countries where there is a marked shortage of teachers in general, and of chemistry teachers in particular. As a result, these countries are inevitably trying to push through various accelerated and shortened teacher-training programmes, which cannot fail to affect the quality of such training. This is an acute problem, the solution of which needs further research with a view to producing recommendations about the best possible curricula for accelerated teacher training. In the highly developed socialist and capitalist countries, a trend towards a rise in the number of chemistry teachers is also apparent although, at the same time, most of the capitalist countries are increasingly faced with the problem of the unemployment of such teachers.

Numbers do not tell the whole story, however. Equally, there are increasingly pressing calls for a greater number of 'good' teachers. (6) This is a much more complicated problem to solve. Educationists of the classical school used to say 'A bad teacher teaches the truth; a good teacher teaches how to find it'. The problem is for all teachers to be 'good' in this sense of the word. One can partly agree with the description of the 'good' teacher given by the author of an article on this problem (7) but, as I see it, the crux of the problem lies in the teacher's ability to do his work in a creative manner. This is why it is highly important, in the system for training a 'good' teacher, to ensure not only that he assimilates at first hand all the latest scientific discoveries in chemistry as well as in psychology and in the science of education, but also that he acquires, while still a student, an aptitude for scientific research. The curriculum for a chemistry teacher's training is an extremely complicated matter. Where can chemistry teachers best be trained? In university chemistry departments, or in the education departments of university colleges, which offer a special course for teachers in chemistry and biology, chemistry and physics, etc.? The practice of such departments is to give a great deal of attention to the teacher's training in educational psychology (cf. for example, 5 and 8) and this is laudable, but his chemistry education suffers since the number of hours allotted to it is approximately half the number offered in chemistry departments, and this inevitably has an effect on the quality of training. I feel that in any teacher training, the chief and fundamental task is training the teacher in his special subject and only afterwards in psychology and in education. A teacher must first and foremost have a thorough knowledge of his subject and only then of teaching methods. This is why any joint course seems to me less effective than training a 'straightforward chemist'. Joint courses may be all right for teachers in junior chemistry classes or for general science courses, but teachers for senior chemistry classes in secondary schools should be trained in university chemistry departments. Whether chemistry is better combined with biology or physics is open to discussion. A link with physics and mathematics seems the best combination.(9) However, the practical work of teachers trained along these lines in Denmark, France and a number of other countries shows that such teachers give significantly more weight to the teaching of physics and the pupils' knowledge of chemistry is markedly poorer as a result. The best results are consequently obtained by training a 'straightforward' chemist.

The choice of the teaching profession and, in this instance, choosing to be a chemistry teacher, is of great social significance. The number of teachers and the number of 'good' teachers depends directly on the number of young people choosing this hard but influential work as their career. It is difficult to describe this social problem in general terms as it is closely bound up with the social structure of the modern world. Here, the socialist countries are faced by one set of questions and the capitalist countries by another, and the problem is being tackled variously in the developing countries according to whether their society is developing along socialist or capitalist lines. I suggest that it is the socialist system which provides optimum conditions for the development of education. The experience of the U.S.S.R. and other socialist countries shows that under the socialist system the intellectual and material stimuli provided for school and university teachers are such that young people are strongly attracted towards the teaching profession.(10, 11) In socialist countries, the distribution of graduates among the different branches is planned and every graduate is guaranteed employment by the State.

In capitalist countries, there are many complex social problems associated with the choice of the teaching profession. The system of competitive examinations for posts in secondary schools (5) can be justified in many cases, but if a graduate cannot look forward to guaranteed employment, this makes him very dubious about choosing teaching as a career. The problem of teacher unemployment is a serious one. I believe it is for mankind to ensure the most favourable social conditions in which young people can train to become teachers. From time immemorial, children have been taught to show an especial respect and love for their parents and teachers. In the modern world, which is the world of speed, technology and progress, education, respect for the teacher's work and creation of the objective conditions most conducive to it should be among the most highly valued goals devolving on the individual and on mankind as a whole.

THE CHEMISTRY TEACHER

In what do the new trends in the training of chemistry teachers consist? In my view, the most evident trends lie: (a) in the attempt to establish a unitary, coherent system of chemistry instruction at secondary school and university; (b) in seeking to broaden considerably the range of chemistry courses at secondary schools, so as to include many aspects which until recently were the province of the university and, consequently seeking to broaden even further the range of university courses, as a result of transferring various elementary or purely formal parts of the course from the university to the secondary school. I shall call this trend the 'merging of the levels' of education.

Both trends are clearly reflected in various countries. The matter is discussed when analysing the standard of chemistry teaching, and the direction in which it should develop, in the Federal Republic of Germany, the United Kingdom, India, Japan and the U.S.A.(5) It is also being actively discussed and worked on in the U.S.S.R., particularly in connexion with the introduction of universal and compulsory secondary education,(10, 12, 13) and is receiving close attention from chemists in the German Democratic Republic, Czechoslovakia (14 to 17) and other socialist countries. I would particularly like to stress that we are here considering a trend in teaching theory and practice. The secondary school is taking over large sections of chemistry teaching which only 10 to 20 years ago were the province of the university. This is true of such branches of inorganic chemistry as the structure of matter, oxidizing and reducing reactions and qualitative analysis as well as a considerable part of organic chemistry, including such problems as the structure of benzene (naturally on the qualitative level) together with the fundamentals of physical chemistry. In this connexion, it is interesting to take a look at modern secondary school textbooks, as they provide vivid evidence both of the establishment of a unitary, continuous system embracing secondary school and university and of the 'merging of levels' (I have in mind the textbooks edited, for instance, by G. Seaborg, U.S.A., L. A. Cvetkov, U.S.S.R., etc.).(17, 18)

Naturally this merging of levels imposes particular demands on the teaching of chemistry at university level since now, and even more so in the future, the university graduate who is going to work as a secondary school teacher must be capable of teaching to the standard which these new trends require. The content of the university course must grow more quickly, in volume and quality, than that of the secondary school course. Only then will the merging of levels develop progressively.

For example, at my own University of Odessa, the new curriculum in the chemistry department, introduced over the past few years, provides for the following five-year course of study and laboratory work (figures indicate the number of hours): higher mathematics, 352; special branches of higher mathematics, 84; physics, 330; theoretical physics, 54; structure of matter, 48; quantum chemistry, 54; inorganic chemistry, 352; analytical chemistry, 263; organic chemistry, 368; physical chemistry, 350; chemical crystallography, 36; colloid chemistry, 90; chemical technology and construction of models of technological processes, 172; physical methods of analysis, 90; physical methods of research, 64; special lectures on particular branches of chemistry and special practical work (on special subjects), 520; the history of the Communist Party of the Soviet Union, 170; philosophy, 140; political economy, 140; scientific communism, 70; psychology, 40; educational psychology, 72; teaching methods, 50; foreign language, 300; physical education, 140. It will be seen that a chemistry graduate from this university receives a broad education in physics and mathematics (including, as a compulsory subject, the use of computers for solving problems in chemistry). Chemistry is taught on the basis of quantum theory concerning the structure of the atom and the chemical bond, modern stereochemistry, theory of the mechanisms involved in chemical reactions and the kinetics and thermodynamics of chemical processes, including correlation equations and an introduction to the numerical theory of reactivity. In their fourth year, students enrol voluntarily for one of the special subjects offered. There are seven such subjects at Odessa University: inorganic chemistry; analytical chemistry, physical chemistry; the physical chemistry of polymers; organic chemistry; the chemistry of natural and synthetic physiologically active substances; and chemical methods for preventing pollution of the environment. While the courses on these special subjects, which play an important part in giving present-day students a wider range of training, include lectures and practical work, most of the 520 hours devoted to them are spent on research in accordance with a highly individualized study plan. During the third, fourth and fifth years of study, each student carries out five months' practical work in a chemical factory or research laboratory and two months' teaching practice in a school.

Industrial and teaching practice are carried out under the supervision of university teachers and instructors made available by the factories and secondary schools. In the factory, the student performs definite laboratory or workshop tasks. In the secondary school, he must prepare in collaboration with his supervisor, and give unaided, not less than six lessons. Each of these lessons is given in the presence of supervisors and fellow-students and is then jointly discussed. The course ends with each student preparing a diploma thesis covering experimental work on a topic relating to the scientific research of the department in which he has been working, and defending it in public before the State Examining Board.

This curriculum is not vastly different from the one introduced in 1965, but all the changes made are designed to give the students a more thorough grounding in physics and mathematics. There is one further important question arising from this curricular approach (shared by all Soviet universities) which leads to lively discussion from time to time, namely whether it is better to train chemistry teachers for secondary schools: (a) by adopting a special syllabus designed solely for future teachers; or (b) by using the same syllabus for all graduates - research workers, future workers in industry, and teachers - alike. I am in favour of a standard university syllabus for the training of all chemists, whose future place in society is in the last resort determined by their studies and subsequent work.(8, 20) Any graduate research worker, worker in an industrial laboratory or technologist would find a knowledge of psychology and the science of education useful and it could only help him in his work. Similarly, experience of working in industry or a research laboratory and a knowledge of the methods of scientific research are exceptionally useful to a teacher. For this reason, a standard training course for all graduates, paying due attention to educational science and psychology, appears preferable to any kind of narrow professional training, e.g. of teachers, of research workers, etc.

The problem of what constitutes a 'good' teacher has been mentioned above. In the opinion of D. Hamachek,(7) he is amiable, unassuming and upright, wise, with a sense of humour and a gift for teaching, adaptable and with a high standard of general culture and education. It is possible to agree with much of what this author says but, in my submission, a 'good' teacher must also have scientific curiosity and creative ability. Only if he combines all the above qualities (to which should be added devotion to duty) with a high standard of professional training and creative ability, can he be said to be a really good teacher. The ability to create, to do original scientific work and inspire his pupils to do likewise, is learned at university. The curriculum described above, or any other similar curriculum, represents only one of the ways in which a good teacher can be trained. The curriculum merely provides objective conditions making the training of such teachers possible. The main aim in education, however, is to have a creative spirit and atmosphere in the particular university or university department concerned. Even the best-designed curriculum is doomed to failure if the teaching staff themselves are imbued with a formalistic, dogmatic, uncreative spirit.

A creative atmosphere, a high sense of principle, civic-mindedness and frank and friendly relations between teachers and students - such are the factors most conducive to the training of good teachers. This is why the very best teachers usually come from those groups in which there is a high scientific standard and where the creative spirit permeates the whole teaching system.(21)

Everything said above applies to the training of secondary school and university teachers in equal measure. It is the practice in most countries for the teacher being trained for university work to undergo supplementary training in the shape of postgraduate work of various kinds (5, 10) and levels (differing in the length of training, standard required for theses, etc.). There is indeed a general trend at present to demand of the teacher a higher standard of all-round education, better knowledge of chemistry in general, physics, mathematics and his chosen special subject and also a more advanced level in his diploma thesis. However, supplementary training should not be regarded as compulsory. There are cases where young people, selected for university teaching straight after completion of their five-year course have tackled their jobs superbly and have subsequently defended their theses brilliantly, without any supplementary training, continuing to study and to carry out research in the course of their teaching duties.

The training of a university teacher depends to an even greater degree on the standard and rhythm of scientific life and the creative atmosphere among those working in the departments. A professor who really cares about ensuring the continuation of his work must, like a gardener, tend the bright, new blossoms, i.e. the young scientists and teachers, attentively. Experience shows that this process should begin in the very first year of studies. It is always possible to find inquiring minds, fine young people burning with the desire to engage in original scientific work. It it is possible, such fresh young people should become accustomed from the very first day to serious work in a creative scientific group; their fifth-year degree work will be better than any thesis produced by an ordinary postgraduate. All this can be called a search for talent and it is vital that this search be conducted. I would even go further and contend that the search should be begun still earlier, in the secondary school, and for this purpose direct contacts between the university and the secondary school are extremely important. In any case, such contact is necessary for very many other reasons which will be mentioned below.

Thus the prerequisites for training a good university or secondary school teacher are an atmosphere of original scientific work and the existence of teams of scientific workers who, in their own person, set an example of honesty, sincerity, devotion to duty and civic-mindedness. Bearing in mind what has been said above about the merging of levels and the rapidly developing trend towards extending the range of chemistry teaching in the universities, the requirements to be met by an individual selected for future university teaching are being raised considerably and must be higher than the requirements to be met by any other graduates.

Lastly, reference should be made to one further problem concerning the training of teachers for higher education. All chemistry teachers working in polytechnic, technological, teacher-training and other specialized higher educational establishments should be university graduates, since only a university education affords a sufficiently wide outlook and an insight into scientific thinking.

Quite a few books have appeared recently on the application of teaching machines to the training of chemistry graduates.(cf. e.g. 22) I believe that such machines could be very usefully employed on a wide scale for the purpose of developing and improving the directed study system: thus they can be used effectively for directing independent work on projects in special classes, for providing advice with minimum teacher participation, for preparing for laboratory research and to some extent for checking on the progress of work. But the most important element in teaching is, as it always has been, contact between teacher and student, the immediate transference of experience and the initiation of young people into the living traditions of a particular scientific community.

A very vital and important problem is that of further training for both secondary and university teachers. This problem presents specific features at each particular type of school. Let us look first of all at further training for secondary teachers. There can be no doubt about how urgent this problem is. A large proportion of secondary school teachers in all countries (5) left university or other higher educational establishments 10 to 20 years ago and sometimes even more. Are they now ready to teach at the level required and to grasp all the new trends now apparent? Obviously not. In one IUPAC report (5) it was stated that if an educated man from the fourteenth century were transferred by time machine to the seventeenth, he would be agreeably surprised at the broadening of intellectual interest but would, in the main, understand the educated people of the time. Can we as readily believe that scientists of the late nineteenth century would be able to converse freely with those of the twentieth century? Scientific progress has become so rapid that knowledge now becomes out of date more quickly.

This is why further training for teachers represents a most important problem of no less significance than the problem of their initial training. Experts estimate that, at present, the quantity of ideas, information and concepts a teacher has to assimilate doubles during his studies and increases eightfold in the course of his working life; and the rate of increase will be further accelerated in the future. This means, according to present estimates, that a university graduate will need to repeat his higher education at least four times during his working life. Should he not do so, he will necessarily be a drag on scientific and social progress and hinder the optimum development of education.

There are several possible ways in which secondary school teachers can receive further training. The first is by self-improvement, e.g. reading newspapers and books, consulting people, maintaining constant contact with one's alma mater, going to various lectures, etc. This depends to a great extent on a person's character. My belief is that a strong, well-balanced, dedicated and energetic person (a 'good' teacher) can do a great deal in this way. To achieve self-improvement, of course, the material possibilities must exist, the person concerned must have free time and there must be the necessary objective conditions e.g. the opportunity to buy books, to subscribe to journals, to attend lectures and maintain a link with the university. Nevertheless, even under the best possible conditions, such a person will not have enough opportunities for discussion, human contacts or participation in university life. That is why, whilst not excluding self-improvement, we must look at other ways in which further training can be provided.

There are, moreover, some secondary school teachers who for a variety of professional, psychological or material reasons are simply not inclined to self-improvement. It should also be added that in many countries (4) textbooks, far from being conducive to self-improvement, actually serve to widen the gap between modern scientific knowledge and the level of teaching in school.

Another possibility is to establish a system of university refresher courses for teachers. Various systems of this kind are in operation in the U.S.A., the Federal Republic of Germany, the United Kingdom, Denmark, Sweden and other countries and considerable importance is attached to them. According to the IUPAC report, preference is given to 4 to 10 week courses which include both lectures and laboratory work.(5) Courses of this kind enable school-teachers to become genuinely immersed in the life of present-day communities of chemists and to imbibe the spirit of modern scientific ideas. As a rule, these courses are arranged for groups of 50 people who attend lectures, discuss problems in seminars and carry out individual work. The available information (5, 22-24) indicates that, in the U.S.A. for example, a system of this kind caters for about 25 per cent of all chemistry teachers.

In Denmark there is a universal system of refresher courses, and practically all teachers systematically attend such courses at universities. In France, Sweden and many other countries also, considerable experiences of refresher training for teachers has been acquired but the existing systems are not compulsory on a country-wide scale.

In the U.S.S.R. and other socialist countries, a system of refresher courses for teachers also exists.(10) In the U.S.S.R. it is a State system and is compulsory for all teachers, chemistry teachers included. Every teacher takes a refresher course once every five years, these courses being held at universities in the various regions of the country. The work is planned on a 144-hour programme which includes lectures by the universities' leading professors and laboratory work. While studying at the university, teachers receive their normal pay and are accommodated in a hotel.(10, 21) In many other socialist countries, e.g. the German Democratic Republic, Poland, Cuba, Czechoslovakia and Hungary, there are also unified systems of refresher courses for secondary school teachers organized on lines similar to those described for the system in the U.S.S.R.(22 to 24)

In both the U.S.S.R. and the U.S.A., a teacher is given an appropriate certificate at the end of the course. It is interesting to note that the refresher courses of all countries lay stress on a repetition of the basic chemistry courses at a modern level. In my view, this is right. A refresher course should first of all go over the basic chemistry course with the teacher and only then tell him about some of the latest methods of research and new branches of chemistry. Considerable attention is devoted during refresher courses to psychological and educational matters. The further improvement of refresher courses for teachers is exceptionally important and is a necessary new trend in the education system.

A third way, closely linked with the first two, is the regular revision of textbooks and syllabuses, so encouraging teachers in their efforts to improve the standard of their teaching.

Where higher education is concerned, the problem of further training assumes somewhat different aspects. This problem is closely bound up with that of the teacher's original scientific work (and in this connexion it should be pointed out that even in secondary schools, particularly in those where there is a good school laboratory and the school is near a university centre, research is now widely recognized as a very effective means for a teacher to improve his qualifications). The best form of continuous further training for a university teacher is participation in reresearch in an appropriate scientific community, work in other laboratories in order to learn new research methods, and a constant introduction of new elements into his teaching work. In addition to this, it is essential to organize lectures on the latest achievements in education and psychology. We have had such lectures in our university for a number of years and they have proved highly effective (70 hours in the course of a year). Equally good results are obtained by instructing university chemistry teachers in the methods of computational mathematics and practical work on computers.

Methods such as these are used in practically all countries but the U.S.S.R. is the only one which, for more than five years, has had a compulsory nation-wide system of refresher courses for all teachers in higher educational establishments. Teachers attend such courses once every five years on full pay, and the State pays their fare to the place where the course is being held or to the faculty providing further training in their particular specialty. Under this system, the universities act as further training centres for teachers from other higher educational establishments. (21)

The problem of the link between the university and secondary schools goes far beyond the problem of further training for teachers. The universities should, ideally, exercise a genuine influence over the whole life of the secondary schools, including their pupils' choice of future career. To achieve this aim (where the teaching of chemistry is concerned) a large number of important organizational and other steps need to be taken.

These include: (a) the organization of televized lectures from university centres about topical problems of scientific development, including chemistry; (b) the organization of a system of public lecture centres (including some for school-children) on problems in chemistry; (c) the organization of regular excursions for school groups to university laboratories, with an explanation of the problems on which they are working; (d) the organization of school chemistry clubs where children, under the guidance of a teacher or students, could carry out experiments on subjects not included on their syllabus; (e) selection of the best pupils for work in a university laboratory; (f) the holding of chemistry competitions and contests for school-children, in schools and at universities; (g) the organization of summer chemistry schools, in universities, for school-children particularly interested in chemistry; (h) the organization of optional chemistry courses for school-children, also at the universities.

By these means it will be possible to link schools and universities together in a unified educational system, infuse fresh content into the school-teacher's work and help the secondary school leaver in his choice of career. My own practical experience clearly underlines the value of such measures.(8)

This article has examined some new trends in the training and further training of chemistry teachers and, more generally, in the development of chemistry teaching. Although not exhaustive, it will, one hopes, draw the attention of the chemical fraternity at large to the essence of the question under discussion and will make it possible, by further constructive discussion, to elucidate those matters and problems which have received insufficient attention.

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Promoting improvements in chemical education at the national level

by G. Illuminati

INTRODUCTION

The improvement of chemical education is due to several factors. Some of these are directly related to the evolution of chemistry, of science in general, and of their scope. Others are connected with the specific needs of each country, depending on its economy and social characteristics. Schools and universities are faced by the problem of adapting chemical education so as to present the discipline in an up-to-date form and to meet the requirements of the country concerned. The ability of the educational systems to make changes ensures that improvements are possible and that they are quickly assimilated. This ability is obviously a function of the procedures by which changes take place. A critical analysis of the difficulties hampering the processes involved in efforts to improve chemical education in various countries is helpful in order to overcome those difficulties and devise suggestions. In the present paper the writer does not pretend to carry out a complete analysis of this kind because reports are relatively meagre on this point, but he will attempt to survey the main types of strategies followed by individual countries to improve chemical education in their schools and universities. It is hoped that this will stimulate further interest in the comparison of processes for change and that, in the end, more information will become available on the capacity to make changes.

Apart from references to specific articles and private communications, a number of recent general references (1 to 6) have helped in providing useful information for the preparation of this paper.

THE SCHOOLS

As regards chemical education in the schools, initiatives for improvement are found to be of different kinds, ranging from the activity of individuals and/or associations to governmental plans.

One of the most important examples of projects initiated by individuals and carried out through non-governmental schemes is provided by the CHEMStudy project in the United States of America.(2) Stimulated by recommendations emerging from a survey by the American Chemical Society, on the teaching of chemistry in secondary schools, the project was initiated in 1960 by a group of university scientists and high school chemistry teachers to develop new curricula. It was sponsored and funded by the National Science Foundation and by two universities in California. It produced a text, a laboratory manual, and films. Its success may be measured by the large proportion of high school chemistry classes adopting the project in the U.S.A., by the widespread interest aroused outside that country (it has been translated into 12 languages) and by the extensive circulation of the books developed by the project. The large diffusion of the CHEMStudy project among American schools is certainly a sign of their ability to assimilate improvements (TSS: 12,000-500,000-7,000).*

One of the most important projects in the United Kingdom, the Nuffield Science Teaching Project, was started in the early 60s by high school teachers (Association for Science Education) with the financial and organizational support of the Nuffield Foundation. The basic idea was similar to that of the CHEMStudy approach in that it was recognized as essential for any improvement in science education to 'have the time and the people to think about things in a concentrated and in a continuous way'.(3) The Nuffield Project was concerned with curricula, as well as teacher training and examinations.(2, 7) By 1967 it had produced as many as 50 books including student, teacher, and background texts, with a circulation of 300,000 copies. Although it was designed for the organization of high school science studies in the United Kingdom (for example, O-level chemistry courses and, later on, A-level chemistry courses) the Nuffield techniques were adopted in other countries (East Africa). (TSS for the A-level chemistry course (1): 150-2,000-64)

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*By TSS we mean the main implementation figures based, whenever available, and unless stated otherwise, on the adoption of the entire programme (number ofteachers - number of students - number of schools) according to the Eighth Report of the International Clearinghouse on Science and Mathematics Curricular Developments 1972.(2)

The more usual European approach to improve school education is based on actions in a given field initiated and supported by governments, tending to plan changes on a national basis. There are several indications that this planning approach may very effectively lead to the development of chemical education.

In the Netherlands, the introduction of a new system of secondary schools ('mammoth law') called for the renovation of chemistry curricula through an appropriate government commission. It is a seven-year plan,(2) ending in 1977. The project is supported by the Department of Education and Sciences as well as by the Royal Netherlands Chemical Society (TSS: 75-4,000-50). One of the interesting features of the 'mammoth law' is the provision of the appropriate tools to make educational experiments possible with a view to further structural changes.(8)

In Denmark, frequent changes in the educational system have been recorded in recent years.(9) A considerable freedom is granted to teachers with respect to teaching methods and choice of textbooks. However, improvements in the teaching of chemistry suffer from the limited number of teaching hours, which are fixed by law. For example, it would not be possible to develop any course comparable in scope to the Nuffield System or the CHEMStudy Project.

The White Paper on Education (10) recently produced by the British Government is no doubt an important, though indirect, effort to improve education in chemistry as well as other sciences. The document, which is based on official reports, contains an analysis of education at all levels intended to lead to overall planning up to 1981. It reflects a well-balanced position between responsibility vested in a central government and confidence in the educational abilities of the individual institutions and their staff, leaving much room for flexibility and autonomy.

The Scottish Secondary Science Schemes (2) were initiated by the Scottish Education Department and the Consultative Committee on Curricula and supported by the same Department in conjunction with local authorities. They started in 1962 and have already covered the entire student population of the 12 to 18 age group.

A typical example of a generally planned system can be found in the Soviet Union.(11) A law stating the relations between school and life and the need for further development of the public education system (1958) gave rise to several subsequent steps by the public education authorities in conjunction with the Academy of Pedagogical Sciences. The Ministries of Education of the Soviet Republics eventually asked (1963) the Academy of Science of the U.S.S.R. and the Academy of Pedagogical Sciences of the Socialist Federal Republic of Russia to form a mixed commission including scientists, teachers, and methodology experts to analyse curricula, teaching materials and teaching processes. The Commission consisted of several sections (mathematics, chemistry, etc.) and involved 72 members of the Academy of Pedagogical Sciences, university professors, school teachers and pedagogists representing a total of more than 500 people. Their work started in early 1964; the proceedings were published in specialized journals under the series title Discussion on the teaching contents in secondary schools. In the period 1965-1966 the Commission published three drafts for curricula and study plans, the first two being made available for criticisms and suggestions by scientific institutions, universities, and schools. The third draft was presented to the Central Committee of the Communist Party of the U.S.S.R. and to the Council of the Ministries of the Soviet Republics, and recommended to the Ministries of Education as a basis for the preparation of new plans, curricula, and books for secondary schools. At the end of 1966 it was decided to fix the year 1970-71 as a deadline for the implementation of the changes in the whole country.

In France, as part of a general plan for the improvement of education in schools, a commission on the physical sciences and technology was created by the Ministry of National Education and designated the Lagarrigue Commission after its chairman.(12) The Commission consists of about 60 members, including general inspectors, university professors, teachers from classical and technical secondary schools, industrial representatives, and some experts in mathematics and the biological sciences. Its task is a broad one and includes the reform of curricula as well as the training of teachers. The French approach suffers from a certain degree of uncertainty, i.e. the fact that a structural reform was under way and that no member of the Commission participated in the discussions on the reform.

In Japan several steps have been taken to improve chemical education.(13) The Ministry of Education is a major factor responsible for the changes. It is gratifying that nowadays many officers in this ministry demonstrate their appreciation of the importance of science education and, in particular of chemical education, by encouraging research in these areas. The courses of study and their contents are periodically revised (every 10 years or so) by consultative committees. The highest consultative body is the Science Education Council, composed of scientists, staff of teacher-training colleges, and school teachers. Among other tasks the Council reviews projects for new courses of study when in their final form and has promoted the establishment of nearly 100 classes of science-mathematics courses at the senior high school level. Science centres for the retraining of teachers through refresher courses are being created in each prefecture. At present, the capacity of these centres is such as to ensure that one-week courses are taken by every teacher once in five years. Improvement in laboratory equipment has been made possible by the Science Education Promotion Law, which allows for concrete financial contributions from the central Government to the local authorities running the schools.

In India the Experimental Project on Teaching of Science and Mathematics (middle school stage and senior high school stage) was guided by the Department of Science Education (National Council of Educational Research and Training - NCERT) with the collaboration of Unesco.(2) It consists of a comprehensive study to develop new syllabuses and provide new instructional materials. TSS (middle school stage): 1,700-220,000-580.

There are three institutions in India making cooperative efforts to improve science education at all levels.(14) They are the NCERT, the University Grants Commission (UGC), and the National Council for Science Education (NCSE). Summer institutes were started in 1963 on the initiative of these three institutions and were conducted by several university departments with the cooperation of US-AID, of the National Science Foundation, U.S.A., and, in some cases, of the British Council. The institutes served as training centres for teachers. More than 3,000 teachers were trained, using materials developed by American and British projects. Furthermore, NCERT set up study groups in chemistry with university professors as directors and school and college teachers as members. The study groups aim at the preparation of new teaching materials such as texts, laboratory manuals, and teachers' guides. There are already summer institutes using study group material exclusively (Regional College Education at Mysore, 1971).

Another nation-wide, government project, the 'Modernization of mathematics and science syllabi', is being carried out in Pakistan in collaboration with UNICEF.(2) It started in 1966 and involves the entire school population. TSS: 70,000-1,940,000-5,500.

The need for active cooperation with scientists has already been stressed. In this connexion there are several examples of government-controlled schemes conducted under the direct sponsorship and funding of certain universities and research centres.

In Israel the Rehovot Chemistry Group was originated by the Committee for the promotion of the teaching of chemistry (Ministry of Education) and supported by the Weizmann Institute of Science, the Ministry of Education, and Unesco.(2) It works in collaboration with leading scientists and plans to take care of the entire population in secondary schools since 1965 (age 15 to 18). TSS: 40-6,000-30.

In Mexico steps to improve chemical education are being taken by the National Council for the Teaching of Chemistry in cooperation with the National Association of the Universities and Institutes of Higher Education.(15) Teacher training at the upper secondary school level is being carried out at some universities. Changes concerning primary and lower secondary schools are the direct concern of the Ministry of Education.

In Argentina (16) chemistry courses for in-service training of teachers have been organized since 1961, first by the National Research Council and, later on, by INEC (National Institute for the Improvement of the Teaching of Science, since 1968) and by the cooperative efforts of INEC with the Ministry of Education. Plans for increasing the retraining of up to 3,000 teachers in four years are being made.

In the Philippines a science education centre has been organized by the University and the Department of Education and co-sponsored by UNICEF and the Ford Foundation.(2) The Centre has a full-time staff. It is involved in a three-phase programme, i.e., curriculum development, teacher education, and research in mathematics and science education. TSS (high schools): 36-2,325-22.

There are a few other examples of multinational projects. One is the East African Secondary Science Project covering Kenya, Uganda, and Tanzania.(2) It is supported by the Ministries of Education of the three countries and by the Centre for Educational Development Overseas (CEDO). The courses were developed on the basis of the Nuffield O-level materials with interesting local adaptations. TSS (17): 300-300,000-140.

In the 60s, both the Swedish and Norwegian parliaments passed new education acts decreeing 9-year compulsory education in schools. The new philosophy of education demanded substantial changes in the organization of studies in several disciplines, including chemistry and the other sciences. In 1964 a Nordic Chemistry Committee began work as a joint Norwegian-Swedish project with economic assistance from OECD. The aim was primarily to achieve a modern syllabus for the subject. The project consisted of preparing new textbooks, developing self-instructional materials, and organizing summer courses for teachers and pilot courses for pupils.(18)

We have mentioned several examples of cooperation with international or foreign agencies such as Unesco, UNICEF, CEDO, US-AID, etc., in nation-wide programmes. More limited, but still useful interventions by such agencies are possible and have helped in the realization of a variety of national projects. Thus, in Nigeria an in-service course for secondary science teachers (lectures, etc.) was arranged in April 1972 in cooperation with Unesco.(19)

In Italy summer courses for teachers started some years ago under the sponsorship of OECD. These courses were followed by pilot courses for pupils, conducted whenever conditions were appropriate. The project involved the preparation of a textbook by a university team and was continued by the Ministry of Education in successive years. Difficulties in the continuation of the pilot courses for pupils were found since there appeared to be a need for structural reforms in matters such as the revision of nation-wide curricula and teaching hours, which are fixed by law.

As a follow-up, two-week refresher summer courses are still offered to interested teachers. In the last few years, various regulations have excluded many high school pupils from the final examinations in science courses and have lessened their interest in such courses. A recent survey by the International Association for the Evaluation of Educational Achievement (Stockholm), which was carried out under the sponsorship of Unesco and supported, on the Italian side, by the National Research Council (CNR), Rome, showed some dramatic weaknesses in the upper high school situation of chemistry in Italy.(20)

UNIVERSITY EDUCATION

In most countries, individual institutions at university level are autonomous to varying degrees whether they are controlled by a centralized governmental system or not.(6)

In Canada, the educational systems are controlled by the 10 provinces.However, the efforts of the individual universities to improve education show many variations in detail. In India, education is under the administration of the State governments and is not necessarily subject to the central federal authority. By and large, major support comes from the central government and governmental research agencies, or from the component states or districts. In Brazil, for example, even private universities receive partial support from the federal government and this is now probably true of any country where such private institutions exist.

Government support is not by itself an obstacle to autonomy. For example, in Israel, although more than 50 per cent of the total university budget comes from the Government, the individual higher educational institutions possess complete autonomy in connexion with curricula, admission rules, and organization of degree courses. Decisions are determined by the academic senate or similar authorities.

Autonomy is an essential factor in promoting the diversification of educational approaches and related experiments. In contrast, an obvious drawback to absolute independence is the diversification of educational standards. Traditionally autonomous British universities are known to be characterized by a remarkable uniformity as well as by a high level of standards, but this phenomenon is hardly reproducible elsewhere under similar conditions. In the U.S.A., since 1936 the American Chemical Society Committee on Professional Training of Chemists has been studying the complex problems of determining standards and devising means to evaluate professional education in chemistry at the bachelor level. A set of criteria were established which formed the basis for a list of ACS-approved schools. The efforts of this committee have been very important in shaping the study of chemistry in the United States.

In most countries the autonomy of the individual universities must be reconciled with certain legitimate requirements of a state-controlled system. In this case the responsibility for insuring desirable changes in education is shifted in varying degrees to the government authorities who are supposed to devise ways of assisting the evolution of the educational system in close collaboration with the universities. A structural framework may be laid down by the central authority but it should not be so detailed as to hamper flexibility and experimentation by the individual institution. Even in the case of tighter State control, the framework should be set up in close collaboration with university teachers and scientists. It is this delicate balance between opposing needs which is sometimes missed by the central authorities, thus limiting university autonomy in a harmful way.

Changes in the needs of society and the great increase in the student population in the sixties have impelled governments to plan structural reforms in universities. A general reform has been planned in France and is being steadily applied. Within the framework of new principles the organization of studies may benefit from new educational experiments.

The establishment of new reforms may take a very long time, especially as they must result from a compromise between opposing forces. An interesting approach which may obviate the latter difficulty consists in breaking down the overall reform into several parts.(8) This is what is being done in the Netherlands where the following stages are being considered:

1. A reform of the management of the universities (Veringa Law)
2. A reform of the teaching structure (Posthumus Bill)
3. A reform of the finance system.

Even when the developments connected with those stages are in progress, changes in chemistry curricula are not held back and can be carried out to fit new ideas, such as the organization of course work by teams of professors.(6) The Royal Netherlands Chemical Society, which has had an impact on the improvement of teaching chemistry in the schools, has also played a role in reforming the universities, especially in commenting on the Posthumus Bill with the objective of maintaining high standards in chemical research and postdoctoral training.(8)

Among the fast developing countries, Korea has been taking concrete steps for the last 10 years toward a scientific orientation of the nation.(21) Chemical education has benefited considerably at all levels from the assistance of both the Ministry of Education and the Korean Chemical Society. In particular, graduate education received proper attention in the newly established Korean Advanced Institute of Science, where the courses of studies are given on as flexible and creative a basis as possible.

In Cuba, the main effort is being directed toward the participation of students in the productive activities of the country (22) through a combination of work and study in varying forms depending on the educational level (schools and universities). This combination is encouraged by the creation of schools near working areas and by the increased availability of chemical laboratory facilities.

In order to obtain an accurate picture of national problems in chemical education, several countries have produced national surveys to serve as a basis for suggestions concerning experiments and improvements. Several surveys have been prepared in Australia in the last 10 years.(6) The report of the Markin Committee (1963) resulted in a decision to diversify tertiary education by establishing Colleges of Advanced Education as alternative types of institution to the universities. In Japan the report (6, 13) of the Central Council for Education to the Ministry of Education led to suggestions for the reorganization of graduate studies in view of the need to facilitate the retraining of people in society.

An important survey was recently carried out in the United Kingdom (6) by the Committee of Enquiry into the Relationship between University Courses and the Needs of Industry (1970). It was sponsored by the British Committee on Chemical Education.

Another useful initiative in several countries is the publication of journals in the field. Among those which have appeared in recent years we may mention the Indian Journal of Chemical Education.(23)

Meetings on chemical education have been organized at both the international and national level. The chemical societies are more frequently devoting all or part of their periodic meetings to this topic. At the national level (for example, Hungary (24) and Italy) this is an excellent way to encourage people to become more deeply involved and to stimulate their cooperation in the schools and universities.

Perhaps the best example of a meeting intended to have a direct impact on the improvement of chemical education is the binational conference held in 1969 at Srinagar (India) under the auspices of the Indian National Council for Science Education (NCSE) and the University Grants Commission (UGC) and the United States National Science Foundation.(6) The object of this conference was not merely the identification of problems, but also the preparation of a working document for solving the problems.(6)

Summer institutes, advanced winter and summer schools (such as those in solid state chemistry) and workshops are being extensively used in India as a means of establishing channels of communications and of exchanging experiences. Furthermore, courses are planned for use in the National Science and Technology Plan for Chemical Industries.(23)

In Mexico, updating and refresher courses at the National University have been organized for teaching staff from all universities.(6)

Several interesting initiatives have been taken in the Soviet Union to encourage the learning of chemistry at various levels.(11)

Let us now turn to the establishment of committees having a well-defined, official mandate to decide or propose action for appropriate changes. We have already mentioned the important role of the ACS Committee on Professional Training of Chemists. In Hungary (6) inorganic chemistry courses underwent important changes after a long period of fixed curricula. This was decided on by a committee of the Ministry of Education for all universities in the country. Joint methodological studies were carried out in U.S.S.R. by mathematicians, physicists and chemists to deepen thematics and physics education in chemistry courses.(6)

Recourse to committees of experts who eventually communicate their results to a wider audience for public debate appears to be standard procedure for proposing reforms in several countries. The procedure described in the preceding section for the teaching of chemistry in secondary schools in the Soviet Union may well be applied at tertiary level. A further example is the procedure for reform first applied in the Bulgarian People's Republic in 1973-74.(25) Following a set of new general criteria laid down by the Government in conjunction with the Committee for Science, Technical Progress, and Higher Education (CSTPHE), at the University of Sofia, a committee of 10 to 12 chemistry faculty members and three representatives of the Academy of Sciences worked out a project taking into account the organization of studies at 20 foreign universities and the specific needs of society in their own country. The committee discussed the project in several meetings with representatives of other universities, industry and research institutions, Ministry officials, and their own students and colleagues. The project was then submitted to CSTPHE for final approval.

An important process for general planning of university education in the Federal Republic of Germany was described in a series of reports to the Committee for Higher Education and Research of the Council of Europe.(26) The Federal Republic is composed of 11 'Länder' which, constitutionally possess complete autonomy as regards school and higher education organization. In order to contribute to innovation in the educational systems, to finance and coordinate the efforts of each Land, the Federal Government in June 1970 supported the creation of a Joint Committee for Educational Planning composed of representatives from the Federal Government and the Länder. The work of the Joint Committee is prepared by sub-committees and working parties and is assisted by the recommendations of other bodies such as the Council for Higher Education and Research (consultative body). In addition, a Planning Committee for University Buildings has been set up.

A first draft of an overall educational plan was prepared in 16 months, and was submitted to the heads of governments of the Federal Republic and the Länder. The key year for the implementation of the plan has been fixed for 1975.

For chemistry curricula,(27) the trend implied by the plan consists of a reorganization to provide for an overall duration of studies of not longer than four years (not including research for a Master's degree or a doctorate) and an increased permeability between different educational channels at specific levels. The new state and federal university bills contain an appeal to scientific societies, employer associations and labour unions to contribute within their own fields of competence to this reorganization. Furthermore, university faculty members as well as students were urged to create national advisory committees in the various disciplines. As regards chemistry, the response to the appeal came from the combined efforts of the German Chemical Society, the Bunsengesellschaft for Physical Chemistry and the Dechema, which resulted in a set of recommendations for changing the structure of chemistry curricula at tertiary level(1971). Likewise a nationwide committee to improve chemistry curricula was set up for the first time in 1973, with most universities, teacher training institutions, and schools of chemical engineering represented.

Following the decision of the Joint Committee for Educational Planning and the Planning Committee for University Buildings, and of the Conference of the Twelve Ministers of Education, the Länder proceeded to set up an overall planning procedure for tertiary education in their own regions. For example, much work has been done in this direction by the Land of Baden-Württemberg (on which a report is available) where a large programme of pilot projects has been drawn up to prepare for the creation of so-called comprehensive universities. For each of these projects there is a permanent committee, composed of the rectors and directors of the participating institutions (universities and colleges), and of representatives of the Ministries of Education and Finance. Major current projects are the creation of a school teacher education centre, of a centre for university teaching methods, and of a joint student counselling and guidance service. Chemistry and, more generally, natural sciences benefit from these initiatives. For example, new study courses in chemistry are being organized in Ulm-Eastern Württemberg and a new Institute of Inorganic Chemistry has been built at the University of Karlsruhe. A new Bavarian National Institute for Research into Higher Education has also been established.

Reverting to the work of the Joint Committee for Educational Planning, general nationwide planning has involved many important and often controversial problems, such as the relationships between the Federation and the Länder, the participation of the universities in the process of planning, the internal structure, organization and diversification of higher education, the reform of the decision-making process within the university, the teacher-student ratio, the numerical relationship between full professors and assistant professors.

The complexity of the problems and the fact that cooperative planning within the framework of a federal state was a new experience are factors favouring eventual changes toward a system of central planning and decision-making. There is a danger that, if cooperative planning fails, the educational system will become less flexible and less subject to diversification. Another negative factor is that political compromises involve considerable delays.

The existence of such dangers underline the progress made by the individual Länder, as a result of adopting concrete and empirical approaches instead of engaging in fruitless theoretical discussion based on different political ideologies.

The current developments in the Federal Republic are noteworthy because similar conditions and problems may also be found in several other countries. Great benefit can be derived from a careful and detailed observation of the Federal Republic's experience.

Further examples of mechanisms and approaches for reforming higher education have recently been reported from Norway (28) and Sweden.(29)

It should be noted that there is an encouraging wealth of initiatives throughout the world to improve chemical education. Too often, although not always, as clearly indicated in the case of the Federal Republic, reports have stressed the merits of the changes and have failed to provide a description of the internal mechanism for changes. There are probably more difficulties in the way problems are approached than would appear. It would be helpful to compare precisely mechanisms for changes in order to work out useful suggestions. The present writer has appreciated the frank comments by Prof. Ramakrishma (6) on the inadequacy and obsolescence of the paternalistic structure and organization of the universities (in India).

The dramatic 'immobilism' and the substantial lack of know-how described by the author elsewhere (5) in the Italian educational system is another example to bear in mind. The Italian educational system is too rigid at all levels and the need for autonomy is especially felt at the universities. Furthermore, the country's ability to carry out the appropriate changes is limited because educational reforms have increasingly become a subject of political deals between parties and do not rely on any of the outstanding approaches recorded in this paper. Chemical education in Italy is obviously affected by the present situation. Besides the results of the IAEEA-CNR survey mentioned earlier, it may be noted that Italian universities still do not grant any postgraduate degrees for use in both academic and industrial research careers, although a committee of professors of chemistry has long pleaded for them.(5)

We may note, however, that in a completely different system, in the U.S.A., radical changes, such as the Hammond-type curricula,(5) although considered desirable by many, are not numerous.(30, 31) These basic changes in curricula have been fully introduced at some United States institutions (e.g. State University of New York at Albany) and partially at others.

It would seem that innovations tend to be known and/or used by just a few enthusiasts. In order to encourage improvements in university chemical education, an interesting initiative has recently been undertaken in the United Kingdom by a group of six universities. This is the Chemistry Higher Education Learning Project (HELP-C) which is financed by the Nuffield Foundation.(32) The basic idea is to develop systematic cooperation between several departments in order to work out and test innovations in each of them. This cooperation is believed to have a strong impact on the educational trends of other universities, which may be encouraged to try similar experiments. Some of the main objectives of the project include the identification of a core chemistry and the related core syllabuses, a detailed analysis of the aims of laboratory work and the related suggestions and testing of innovations, and, finally, the search for teaching/learning methods and materials to develop the general attributes a good chemist is supposed to possess (i.e. to communicate chemistry in writing and orally, to define problems and attempt solutions in a logical manner, to cooperate with others in a team, to approach new ideas critically, to make judgements).

The creation of new universities, which is justified by the general increase in student population, provides another excellent opportunity to test new approaches to chemical education (for example, United Kingdom and the Netherlands). The creation of chairs of Chemical Education at universities and the start of systematic research in the field, marked the birth of chemical education as a science and of a powerful tool for its improvement (United Kingdom).

Finally, mention may be made of the Open University (United Kingdom) as a source of innovations and improvements.(33)

An appropriate description of the role and scope of this institution deserves separate treatment and is not attempted here. It should, however, be emphasized that the Open University, through a comprehensive view of the whole of science, the compilation of specially written texts for the science foundation course (five of which directly concern chemistry) as a result of a team effort, the accurately formulated self-assessment questions, to mention but a few of its special features, is bound to have an influence on teaching in other institutions.

CONCLUSION

Both non-governmental and governmental procedures make important contributions to the improvement of chemical education, depending on the structural background of each country. The former allow a greater freedom of choice for experimentation at each individual institution, the implementation of the projects depending on the validity of the proposed changes. The latter tend to concern the entire student population and, therefore, should be subject to a most careful planning and continuous testing of educational results at the national level to ensure that the reforms are beneficial.

In most countries the schools and the universities are controlled by the government authorities to varying degrees. In general there must be a compromise between the need of a given educational institution for autonomy and the government requirements, the universities being usually more autonomous than schools.

When the influence of the law on the educational system is strong, improvements in chemical education depend on it a great deal. It is desirable that the law should have the features of a general plan, rather than being too detailed, and should contain provisions to insure sufficient flexibility for educational experiments and for the diversification of approaches to be possible. Ministries of Education should be organized in such a way as to be sensitive to the changing needs of institutions and teachers.

Whether the educational system is state-controlled or not, the role of the scientists in the improvement of chemical education at all levels has been widely recognized. F. Halliwell's words (3) should be recalled in this connexion: '.... it is important that there is a very close bond between three parties: the top scientists of the country and of the world, those who are concerned with teaching in schools, and those who administer and examine. Unless there is this three body collision ... many of our efforts will be in vain'. We may add that the expression 'administer and examine' should be taken in its broadest political and social sense and that the involvement of the scientists (and the teachers) should apply at all stages of a process of reform.

Several types of action have been used to stimulate improvements in chemical education. They include the determination of reform projects through the work of qualified committees, the collection of data through national as well as international surveys, the creation of centres for the training of teachers, of summer schools and workshops, cooperative efforts among institutions or even countries, the consultative contribution of international organizations or foreign professional organizations. In many cases the chemical societies have played an essential role in the field by stimulating changes in the educational systems, by their concern with standards of quality and by acting as consulting bodies to government agencies.

In the present writer's opinion, there is no single answer to the solution of the complex problems connected with the improvement of chemical education. Many, if not all, of the types of action recorded in this paper should, wherever possible, be utilized. Critical reports on the mechanisms adopted in each country and their effectiveness should be encouraged and made available from time to time for the benefit of the country itself and of other countries. One country's educational system is not a purely internal affair but, rather, is of concern to all.

RECOMMENDATIONS (34)

1. More attention than in the past should be given to the mechanisms by which changes (reforms) in chemical education are carried out in various countries (through the work of qualified committees, the preparation of surveys, the creation of centres for the training of teachers, the support of chemical societies, cooperative efforts

among institutions, the helpful response of educational agencies, etc.)

2. There should be a link between scientists, educators, and administrators to foster greater cooperation and understanding between these groups.
3. Since mechanisms for changes are expected to be fundamentally similar in all experimental sciences, combined contributions from experts of the various branches of science should be encouraged.
4. The collection and dissemination of factual information on national efforts to improve chemical education (including pedagogical studies and studies of language barrier problems) should be provided through the aid of international bodies and taken into account by the responsible educational agencies in each country.

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International cooperation in the improvement of chemical education

by R.W. Parry

INTRODUCTION

Pure science* is one area of human endeavour which recognizes no national boundaries. The ideal gas law and the laws of thermodynamics cannot be modified, amended, or revoked by any legislative body in any land. Pure science is, and always has been, international, even universal. In contrast, the educational system of a country is deeply rooted in its culture. Successful educational programmes must be closely tied to the past activities and cultural heritage of a people as well as to their future hopes and dreams.

Science education occupied a fortunate position - a position which makes it well suited to serve as a bridge between nations and cultures. The science component of science education is firmly rooted in the international laws of the basic discipline; be it physics, chemistry or biology. Its facts, ideas, and techniques reach across oceans, deserts, and political boundaries. On the other hand the education component of science education is deeply rooted in the culture of the nation. Education must reach the minds of the people that it serves. It must touch upon their lives and their personal philosophy; it must become a part of them. This dual nature of science education entitles us to hope that nations which join together to meet the scientific, technological, and educational challenges of the day may also be able to build bridges of friendship and understanding between their peoples. It may not be too much to hope that men of science might serve as small activated catalytic centres from which real international understanding could spread.

The educational process of chemistry, as in all disciplines, is very closely tied to the culture in which the educational system develops. The curriculum must be adapted to build on the background and experiences of the students. Furthermore, it must be directed towards training the students to serve the long-range needs of the society in which they live. The general charge to the educational system is fairly well defined. Methods of meeting the challenge generated by such a charge differ widely and shape the form of projects for international cooperation in chemical education.

CHEMICAL EDUCATION AND CULTURE

Political constraints on international cooperation in the area of chemical education do not usually pose a serious problem. Quite the reverse is true. Many nations, in a spirit of generosity or enlightened self-interest, have been eager to carry their successful science education programmes to any nation which would listen. Teacher-scientists have been pleased to describe their successes to any interested audience, particularly one in a far distant land. A major limitation on such willing international cooperation has been lack of money, but money is not the only problem. Unfortunately many transplanted programmes, like transplanted flowers, have often wilted and died in their new environment. The data suggest that a completely different culture demands some modification in the teaching process.

The educational system is strongly tied to the political, economic, and cultural life of the community. The background, experiences, and expectations of a native tribesman in Africa, or a farmer in Asia, differ markedly from those of a student in a modern, well-equipped urban high school in Continental Europe. The educational approach must reflect these differences in culture. Of even more long-range importance is the fact that the technical problems facing the society of the native tribesman or the farmer stand in sharp contrast to those facing the young citizen of a highly industrialized nation. The chemistry of nitrogen may be important to all, but at a different level. In one case control of air pollution may be the technical goal; in the other, control of soil nitrogen may be the important challenge. The basic laws of science are the same, but the place where the laws make contact with the student's life is different. Directing the student's interest toward the place where his discipline serves society is a strictly local challenge.

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* Pure science is differentiated from the sociology of science in which men and nations compete for honour and credit.

It is further found that the examples used in teaching are most effective if they are very familiar to the student. For example, a reference to the University of Michigan Stadium or the Tejon Pass might be quite effective in Michigan or California, but both would fall flat in Brazil. On the other hand, a reference to the soccer player Pele would excite the Brazilian, but not his U.S. counterpart. Unfortunately references which excite both the Brazilian and the Californian are very limited, and are restricted even more by language barriers. While translation helps the language problem it is not always the ideal answer. Languages differ in detail and in structure to such a degree that fine points of meaning are often lost in translation.

Even within a single nation where language barriers are at a minimum, backgrounds and experiences of entering students may differ so widely that programmes do not transfer easily without modification. This fact has been noted in the schools of the United States where cultural differences between inner city, suburban, and rural students have posed serious educational problems in curriculum design. In my judgement, failure to recognize the strong tie between the cultural background and the training process has contributed in a major way to a fairly widespread scepticism about the value of higher education in science.

Let me illustrate this point. A limited number of nmr spectroscopists doing basic research is essential to the growth of science. In the best of all possible worlds, such men would be allowed to grow and develop in a properly equipped research centre where vigorous and productive interaction with colleagues is a way of life. Students' training in such a laboratory would naturally centre on the use of highly sophisticated and very expensive research equipment. The training would frequently tend to be rather narrow but would be well suited to those intending to remain in a major research centre with adequate equipment although disastrous for students destined to return to a more primitive industrial background where sophisticated research tools and significant professional contact are not always available. The mentor in the research centre may get the Nobel prize, but for the students frustration and unhappiness frequently result. Even worse, significant technical problems go unsolved in their native land. Unless the training programme develops a broad base in science from which a realistic start on local problems can be made under difficult conditions, the education programme has done little to meet the problem of the students' countries. By the same token, the programme has done little to provide the student with real personal satisfaction. Real questions relative to the value of such training have been raised in many forms. Are existing Ph.D. programmes training the mind in logical, orderly thought processes so that the degree holder can successfully solve problems which are far removed from his Ph.D. activity? Extensive criticism of the educational system has been voiced (1) on this issue when many technically trained people have not been able to meet the problems of their society. The question is particularly important for students who plan to return to a less well developed technological environment, but the arguments have been raised in highly industrialized nations. I have very serious doubts that we are even near optimum performance in our training programme.

One might now raise the question, 'Would students from developing countries be better off if instead of sending them abroad to study, the educational programme were transferred to their native land?' To gain insight on this question let us examine in more detail the procedures used for carrying a successful programme from one country to another. This has been done for secondary school programmes, university-level programmes, and even graduate school programmes. Various mechanisms have been developed; some involve exchange of personnel, some involve exchange of materials and texts only, some involve both. Information reaching the IUPAC Committee on the Teaching of Chemistry indicates that the most successful of these transfer programmes are those in which an able teacher or group of teachers in the host country makes a real effort to adapt an imported programme to the particular culture of the host country. In such an adaptation examples and materials of the host country are used. Exchange of personnel is crucial. A combination involving the blending of a sound science programme with the imagination and local insight of dedicated teachers is hard to beat. It is not difficult to endorse the proper transfer of successful programmes between nations, provided that provision is made to put in those local cultural features which are basic to the educational process.

The transfer of graduate programmes provides additional points for concern. In several cases, Ph.D. training programmes in less industrialized countries have been established through cooperation with an outside country or agency. In general, the training programme has generated Ph.D. chemists of skill and competence. In this sense, such training programmes are successful. The young scholars are trained in the best tradition of the industrialized country, using a pre-tested successful curriculum. The problem starts after graduation. Reports given to the IUPAC Committee on the Teaching of Chemistry indicate that most of these new Ph.D.chemists could find no jobs when they completed their work. Their newfound technical skills could not contribute in any positive way to their society despite serious technical problems in their homeland. Many were employed operating streetcars or machines. There was no contact between the educational system of the country and its areas of severe technical difficulty. The educational job was incomplete and many questions have been raised. Is the Ph.D. programme transferred to the non-industrialized country worthwhile? Do the Ph.D. recipients gain enough in intellectual achievement to justify the programme? Are the possibilities of dramatic success for one or two men worth the price of the programme? Is this brand of international cooperation worthwhile? Although others are less pessimistic, the present writer feels that these are very real questions which are truly fundamental to any evaluation of international cooperation in chemical education.

In the opinion of the author, cooperative programmes to give advanced chemical training to selected students in developing countries are very much worthwhile, but they are incomplete. Some adaptation of training programmes to recognize economic reality would seem to be important. The student needs assistance in identifying areas where he can serve. Perhaps a series of industrial internships, if carefully planned, would help to complete the training programme. The student should also be given help in adjusting to the problems of science under non-ideal conditions. In some cases, education of political leaders in the areas of technical concern may be the most important first step in providing opportunities for graduate chemists. Though we are getting close to politics, it is clear that without proper utilization of the graduates, society cannot benefit from a training programme. Without some real benefits to the citizen, few members of society will judge the educational programme to be successful. Since educational systems are ultimately dependent upon tax revenues for long-term support and upon cultural patterns for general guidance, no programme in science education can afford the luxury of neglecting the views and opinions of those who are served. This is not to say that individual programmes must be subjected to detailed political evaluation at frequent intervals. Indeed, this could be quite disastrous to a developing educational system. The art of detailed programme evaluation is still not refined and methods for obtaining feedback are still far from satisfactory. Still, those responsible for programmes in chemical education must not close their eyes to those obvious flaws which are certain to have political impact.

In summary, it is now quite clear that the teaching of chemistry is an area where it is realistic to expect vigorous international cooperation. A number of significant cooperative programmes have already been started. The data accumulated so far indicate that true cooperation, with proper modeling of the programme to fit the cultural and economic patterns of the host country, is essential if maximum benefits are to be obtained.

In the next section more detailed information on specific cooperative activities will be presented. In the final section some possible new directions of international cooperation will be outlined.

A REVIEW OF COOPERATIVE INTERNATIONAL PROGRAMMES

This report summarizes cooperative projects for which information was available to the author in September 1973. The topic of cooperation can be subdivided in many ways. The scheme used in this report utilizes basically the level of industrial development of the cooperating nations or institutions.

Collaboration between two or more developed nations

Such collaboration is always easiest when the nations share a common language and similar political systems, but in recent years a surprisingly large amount of cooperative effort has surmounted language and political barriers. Rather general and somewhat informal programmes exist between English-speaking nations such as the United Kingdom, the United States, and Canada. Interchange of lecturers and visitors at the research (graduate) level as well as interchange of information on undergraduate programmes is common. Many cooperative research programmes have been set up through agencies such as National Science Foundation or National Research Council of Canada or organizations such as the Royal Society in the United Kingdom. A typical programme involves one laboratory in each country and permits extended exchange visits of both staff and graduate students for work on collaborative projects. Some private scholarships such as the Rhodes scholarships, the Robert Blair Fellowships (United Kingdom), the Athlone Fellowships (United Kingdom), as well as government fellowships have provided some support for selected British chemists or chemistry students to study abroad. A number of government fellowships (Fullbright, Marshall, etc.) are available to chemists of the U.S.A. and a similar set is available to Canadians.

An important organization providing cooperation in chemical education in Europe is the newly formed Federation of European Chemical Societies. Through their committee on chemical education they have initiated a study of educational degree requirements and programmes in European universities.(2) The goal is to provide comparative information on programmes to be used in placement of students, or in the utilization of graduates on an international level. Many countries, both developed and developing, have expressed a need for such information. For many students the need arises even before the start of a career. As the world shrinks under the impact of jet planes and international corporations, an increasing number of secondary school students take their education in international or multi-national schools. Because such students are frequently faced with the problem of a transfer to a new school during their secondary school training or because the members of any given class may be preparing for many different universities in many lands, teachers of international schools felt the need for an internationally acceptable secondary school leaving qualification, based on a unified programme of studies. Such a programme, called the International Baccalaureate, has been established. Training in chemistry is a part of this programme; it has been described by J. J. Thompson.(3)

Many countries have bilateral cultural agreements. For example, Poland has such arrangements with the Soviet Union, the German Democratic Republic, Czechoslovakia, Bulgaria, France, U.S.A., United Kingdom, Sweden, and others. These arrangements permit exchange of students, professors, and special technical information. In some cases a university in one country may have a special working arrangement with a particular university in another. For example, the Technical University of Wroclaw (Poland) has such bilateral agreements with the University of Kiev (U.S.S.R.), the Technical University of Grenoble (France), and the State University of Oregon (U.S.A.). The Boris Kidric Institute in Yugoslavia has bilateral agreements with Yeshiva University and Ohio State University in the U.S.A. Similarly, Lehigh University in the U.S.A. has an agreement with Rudjer Boskovic Institute in Yugoslavia. Between Hungary and Czechoslovakia there are good connexions in the postgraduate training of chemistry teachers, and the Scandinavian countries are closely linked with each other. They also have bilateral agreements with many nations. While many bilateral exchange agreements such as those mentioned above, and such as the agreements between the U.S.A. and France, Bulgaria and Italy, or the United Kingdom and Japan, are directed toward cooperation in basic science, they have a direct and positive impact on graduate education in chemistry.

The foregoing summary represents only a small fraction of the current cooperative activities between developed nations, but it does indicate something of the type of activity in progress. Developed nations are frequent participants in international conferences. These are listed separately.

Collaboration between a developed and a developing country

Over the past 25 years many programmes involving developing nations have been initiated. Several such programmes are outlined here. The Government of India has felt keenly the need for training its people in chemistry. Cooperative programmes with many nations have been carried out. About 1960, the National Science Foundation of the U.S. and the National Committee on Science Education of India undertook a cooperative programme for the development of India's scientific base. At first the programme involved primarily summer institutes in which American scientists, paid by the National Science Foundation, conducted summer classes. In 1969 an Indian-United States conference (4) held in Shrinagar and Bangalore, recommended additional development which included: (a) curriculum development at the college level, (b) integrated laboratory courses, (c) college development programmes with emphasis on development of individual colleges and improvement of their scientific leadership, (d) presentation of national lectures on frontiers in science, (e) improvement of research support, educational facilities and libraries, (f) the development of new teaching materials, and (g) provision of in-service training for people in all branches of chemistry. Some of these recommendations seem to have borne fruit. For example, national lectures on the frontiers of science are held. Winter schools in solid state chemistry have been held at an advanced level with professors from India, the U.S.A., and the United Kingdom participating. Proceedings have been published as books. Another recommendation suggested a programme to provide in-service training (adult education) to practising chemists and teachers. In answer to this, American Chemical Society short courses in various branches of chemistry have been widely and effectively used.

During the last five years (1968-1973) summer institutes involving cooperation between India and the United Kingdom have been very effective. Such institutes have been held in the University of Poona with British consultants as co-tutors alongside Indian university staff. Initially these institutes were concerned with an appraisal of the British Nuffield O-level chemistry programme, but in recent years the emphasis has been on Nuffield A-level chemistry (secondary schools). In every case, however, the participants, who have numbered about 40 and who have been recruited on an all-India basis, have studied the Nuffield Schemes (British) in relation to Indian conditions.

A number of additional cooperative programmes between the United Kingdom and developing countries are in operation. Some of these exchange programmes are coordinated by the Royal Society, London; others are administered and guided by the British Council, the Centre for Educational Development Overseas, and the Inter-university Council. These various organizations may provide specialists or consultants for short- or long-term visits, or they may supply books and materials; in some cases they finance visits to the United Kingdom for selected teachers to attend specific courses. Besides the work in India already mentioned, special projects exist in East Africa, Malaysia and Nigeria. In East Africa the initiative for the programme came from Uganda and Tanzania, largely through the enthusiasm of expatriate chemists working in the Faculties of Education of Makerene College, Kampala, and University College, Dar-es-Salam. In Malaysia the initiative came from the Malaysian government after it decided to adopt the Scottish Integrated Science Programme for the first three years of secondary school training. In Nigeria the collaborative programme has centered around the work of the Science Teachers Association of Nigeria. In all of these cases, programmes were designed to prepare new and suitable curricula and examinations or to adapt successful programmes from the United Kingdom to the conditions of the developing country.(5)

Both New Zealand and Australia have active international programmes in chemical education which focus to a large degree on the countries of the South Pacific and South-East Asia. In recent years a few African students have been accommodated. More than 300 students from Malaysia are admitted each year to New Zealand secondary schools and are provided with free tuition and books. They pay their own living and travel expenses. Smaller numbers come from Samoa, Tonga, Baratonga, Fiji, Singapore, and related areas.

At the university level, both Australia and New Zealand offer opportunities for training in chemistry through the Colombo Plan.(6) Students are provided with travel and living expenses as well as with their tuition and books. They are met by officials to facilitate their introduction into Australia. This is a large programme involving more than 1,200 students in Australia alone. It is significant, however, that in 1971, less than four-tenths of one per cent of these students sought academic training in chemistry. This represents a significant decline from five years earlier. The statistics reflect, in part, changing government interests since the recipient governments determine their own needs and priorities and select candidates for training abroad. Fellowship-holders are expected to return to their homeland. While interest in pure science has been falling, interest has remained high in administration, civil engineering, agriculture, and animal husbandry.

In addition to its Colombo plan participation, the University of Canterbury in New Zealand has special links with the recently established University of the South Pacific in Fiji, which provide opportunities for consultation over courses and examinations. Staff interchange is contemplated.

In 1968 a joint U.S.A.-Brazil chemistry study group composed of senior Brazilian and United States chemists was established to investigate ways and means of creating Brazilian self-sufficiency in advanced fields of chemical research and teaching. The programme sponsored by the United States National Academy of Sciences and the Brazilian Research Council (Conselho Nacional de Pesquisas, CNPq) has as its goal the development of centres of excellence in key areas of chemistry in two major Brazilian universities (the Federal University at Rio, and the University of Saõ Paulo).(7, 8) The programme has involved annual or semi-annual visits to the Brazilian campuses by eight professors from the U.S.A. selected by the Brazilians. Furthermore, a cooperative research and teaching programme, supervised jointly by professors from the two countries is in operation. Each research project has one or more United States post-doctoral students who go to Brazil for a minimum of two years to do research, conduct seminars, and teach. The cost of the programme is shared by the United States and

Brazilian governments and by two petroleum companies. A review of this programme by the joint chemistry study group (8) (Rio de Janeiro, November 23-24, 1972) concluded that the overall programme has been successful in proceeding toward its objectives, but much remains to be done. It was recommended that the programme be extended for two years beyond the original termination date of October 1974.

Cooperative programmes have also been established between CNPq and the Canadian Research Council and the government of the Federal Republic of Germany. Chemistry and other disciplines are included in these programmes which provide for an exchange of scientists and graduate students.

Some of the first cooperative programmes in the teaching of chemistry in Argentina were initiated by the U.S.-based Rockefeller and Ford Foundations in collaboration with the Argentine National Research Council. These foundations still subsidize the activities of the National Institute for the Teaching of Chemistry in Argentina.

Collaboration between two developing nations

As soon as the problems of science and the problems associated with science administration began to come into focus in a given developing country, perceptive men saw the need for collaborative efforts with their colleagues in adjoining lands. In many cases this collaboration has survived strained political relationships. Conferences on chemical education involving the nations of South and Central America have been held. Similarly, conferences and direct staff collaboration have provided ties between chemists of Kenya, Tanzania and Uganda.

Collaboration promoted by international organizations

The largest international programme in chemical education is that administered by the United Nations through divisions such as the United Nations Educational Scientific and Cultural Organization (Unesco) and the United Nations Development Project (UNDP).

The Division of Science Teaching of Unesco set up a number of cooperative projects in non-industrialized nations to develop science education at all levels, from introductory science to the Ph.D. Experts in the discipline (chemistry for purposes of this paper) work with local scientists and educators in programme development. Such experts stay for periods ranging from a few weeks to a few years. If language barriers are to be overcome, longer stays are preferable. Such programmes are of great help in bringing advancing science and technology to otherwise isolated areas. In such programmes, provision is made for both scientists and students from the area to travel to other nations to observe and participate in on-going programmes of research and teaching. One such project is found in Salvador, Bahia, Brazil; another was in Brazilia, Brazil.

One of the earlier projects directed toward development of teaching programmes in one geographical area was the Unesco pilot project for teaching chemistry in Asia, which was started in Bangkok in 1965. The project was phased out in 1971 with the intention of extending the accumulated results to other areas of the world.(9) The goal was to demonstrate the possibility of generating new methods and materials for science education within the context of developing countries. Study groups were formed in most of the participating Asian countries and resource material such as journals, books and special items developed in Bangkok were sent to them. Frequent staff exchanges also facilitated communication. In general, the project made a major contribution to the teaching of chemistry in Asia. An evaluation report is available.(9) Continued interest of chemistry teachers in South-East Asia is being maintained through the efforts of many people.

In May of 1971, the Division of Science Teaching of Unesco, conducted a review of its activities on behalf of science teaching. The following major activities were listed:(10)

1. The publication of New Trends
2. Other publications such as bibliographies, surveys, etc. See, for example, the Survey of chemistry teaching at the university level (11)
3. Meetings of various types to disseminate and exchange information on chemical education improvement
4. Direct communication through visits of staff and Unesco experts
5. Promotion of research on chemical education, including stimulation and support of innovations in design and testing of new methods and materials. For example, the Unesco Field Science Office for Latin America organized a seminar on the teaching of chemistry in Montevideo, Uruguay
6. Advisory and consultative services to member states. The Bangkok Project (9) is one example, but not the only example of this type of work.

As noted earlier, Unesco is not the only United Nations agency promoting international collaboration in chemistry education. A joint project between United Nations Development

Project (UNDP) and the Government of the Arab Republic of Egypt was initiated to establish a Science Centre for the Advancement of Postgraduate Studies at the University of Alexandria. The Centre is being equipped with a central library, research facilities, and essential office services. At present, experts from the U.S.S.R., Poland, Hungary, and India are collaborating with Egyptian professors in setting up the research programme. One of the goals of this programme is to reduce the need to send students abroad for the Ph.D. It is hoped that study in Egypt can help to focus the student's attention upon local technical problems.

The International Union of Pure and Applied Chemistry has been interested in many of the facets of chemical education for many years (i.e. nomenclature, atomic weights, etc.), but it did not formalize its general interest in chemical education until the first committee on the teaching of chemistry was organized in 1964. Since that time the committee on teaching has been involved in a sizeable number of (disparate) activities. Since the committee has a very small budget it must, of necessity, serve as an information centre rather than as an operating unit for extensive programmes. Most of the activities of IUPAC in the chemical education area are listed in the special section devoted to conferences and reports. A few additional activities should be mentioned here. A subcommittee of the IUPAC Teaching Committee is working with other interested groups to formulate simplified nomenclature rules. The committee urges the adoption of such rules by textbook writers in all countries. In view of the important role played by textbooks in chemical education, some effort has been made to provide information on available texts, etc. A display of United States texts in chemistry was held in connexion with the meeting of national representatives to IUPAC in Washington in 1971. Following the meeting, a survey was conducted to determine types of textbooks, sources of textbooks, and ways in which textbooks are selected and used in various countries. A summary has been prepared and can be provided on request to the IUPAC Secretariat in Oxford. A new IUPAC activity is a Newsletter on chemical education which is being published.

The Organization of American States (OAS) has made possible many chemical education programmes in the Americas. Several conferences, listed elsewhere, have been sponsored by OAS. In addition, OAS supported fellowships in chemistry in the University of Buenos Aires. A multi-national programme in chemistry, organized under OAS auspices offers young Latin-Americans an opportunity for graduate study in one of four centres of excellence. These are: Institute of Chemistry of the Universities in Buenos Aires and in La Plata, Argentina; Polytechnical Institute and the National University of Mexico, and the Institutes of Chemistry of the Universities of Chile and of São Paulo, Brazil.

Finally, in considering international activities in the teaching of chemistry mention should be made of the International Council of Scientific Unions (ICSU) which encourages co-operation on all aspects of science teaching around the world.

Conferences and reports

Chemical education involves the transmission of ideas and information. Conferences and reports remain as one of the best available methods for transmitting such material. Many conferences on the international aspects of chemical education have been held and many reports on the subject have been prepared. Selected titles of conferences and reports are listed:

Selected conferences

(a) The role of examinations in determining chemistry curricula. The conference was held in Bangkok, Ceylon in 1968 with major Unesco support and IUPAC participation. A report is available.(1)

(b) Latin-American seminars of chemistry are held every two years and are supported by the Organization of American States.

(c) An International symposium on chemical education was held in Frascati, Italy, 16-19 October, 1969. This meeting was supported by Unesco and several other sponsors. A report is available.(1)

(d) An International conference on education in chemistry was held at Snowmass, Colorado, U.S.A., 20-24 July, 1970. This conference was initiated by the Division of Chemical Education of the American Chemical Society and IUPAC, and was supported by many sponsors. A report is available.(12)

(e) A very successful International conference on chemical education was jointly sponsored in São Paulo, Brazil, by the University of São Paulo, the Brazilian Academy of Science, and IUPAC. The conference was directed toward the educational problems of South America. It was held from 31 August to 4 September 1971. A report is available.(1)

(f) An International conference on chemical education, jointly sponsored by the Polish Academy of Science, the University of Wroclaw, Unesco and IUPAC, was held in Wroclaw, Poland (1973). This was the first of a series of world-wide conferences on chemical education. Present plans indicate that such a meeting will be held once every four years under the auspices of Unesco.

(g) The first Inter-American conference on the teaching of chemistry was held in Buenos Aires in 1965 under the sponsorship of OAS. A report is available.(13)

(h) A conference on university teaching of chemistry for English-speaking African universities was held in Nairobi in 1971. A report was published.

Selected reports and papers

(a) The in-service training of chemistry teachers, IUPAC Information Bulletin No. 31, March 1968. As a result of this study the IUPAC Committee was instrumental in getting the IUPAC Council to adopt the following resolution in 1967: 'in-service training for teachers should be introduced to provide for a minimum of four weeks, preferably three months, retraining every five years for all teachers of chemistry in all countries at the secondary or high school level.' Implementation of this resolution remains as one of the major operating goals of the IUPAC Committee on the Teaching of Chemistry.

(b) A group of four papers was prepared for the meeting of the IUPAC Committee and its national representatives in Washington in 1971. (14) These were directed toward the very important international problem of chemical training for the average, non-technically-oriented citizen. This area is emerging as one of the most important in all of science education.

(c) A Survey of chemistry teaching at university level was published by IUPAC and Unesco (1972).(11) This publication ably summarizes some of the major points in university level chemical education in 22 different countries. Both problems and practices are considered.

(d) For comments on the above report see William B. Cook, International Chemical Education, J. Chem. Ed., 49, 661, 1972.

(e) Every two years, a report edited by David Lockhard is published under the auspices of the American Association for the Advancement of Science and the Teaching Center of the University of Maryland.(15) This report is a comprehensive compilation of available information on curriculum development projects throughout the world. It is strongly recommended.

(f) A major report on science education in nineteen countries has just been prepared (1973) by L. C. Comber and J. P. Keeves (16) under the auspices of the International Association for the Evaluation of Educational Achievement. It deals with evaluation in science teaching.

SUGGESTIONS, PROPOSALS, AND PLANS FOR FUTURE INTERNATIONAL COOPERATION

In discussions held by various international groups during recent years, a variety of activities to promote international cooperation in chemical education have been outlined. In order to obtain value judgements and priority ratings for existing programmes and for new projects which have been suggested by chemical educators around the world, the following suggestions from many sources are outlined.

Toward better international communication

Many of the activities outlined earlier have been directed toward establishing communication between chemical educators. All of the standard techniques including conferences, reports, publications in journals and a newsletter, have been utilized. In this connexion, Unesco envisages a general meeting every four years.

Regional meetings. In the interim between such world-wide meetings it is hoped that regional meetings will be organized by local authorities in collaboration with IUPAC and/or Unesco to consider specific problems and developments.

Computerized mailing lists. It is clear that the system for contacting teachers on the working level is limited in its effectiveness. It has been suggested that a mailing list of representative chemical educators in each country should be compiled on computer tape or that systems of communication through well established channels such as journals, be developed.

Teacher exchange and student exchange. The obvious limitation on exchanges of working teachers and groups of students is financial and would be possible only through the aid of an appropriate financial sponsor.

The creation of panels of international consultants

Over the past few years recommendations for the creation of panels of consultants to assist in areas listed below have been made. The actual mode of operation of each panel would have to be dictated by the problems which it faced and the resources available to it. Some topics are indicated here.

Panel on examination review. Since the examination system is the one pressure point which always has great impact on the educational operation, it has been suggested that an international panel be made available to review examination material provided voluntarily to them by groups interested in receiving such assistance. This topic was debated in the Washington meeting of national representatives in 1971.

Panel on the development and evaluation of educational structure at the university level. (17) Such a panel would provide advice on the organization set-up; academic terms, administrative practices, etc., of a university. It would not be in a position to impose procedures or dictate solutions.

Panel on equivalence of qualifications. In an earlier section it was noted that a real need had been felt for some standardization on a leaving qualification for secondary schools. This gave rise to the International Baccalaureate. Some areas of the chemical community have also felt the need for standardization points in university chemical education.(2, 18) A European survey focusing on this point has been proposed by the Federation of European Chemical Societies.

Panel on continuing education for chemists and chemistry teachers. Such a panel would provide advice and assistance on the continuing education of all chemists including in-service training of teachers. It would be in a position to transmit the experiences of groups from around the world.

Panel on educational techniques, methodology and equipment. The function of such a panel would be to provide advice in the much neglected area of choosing techniques, materials, and equipment in close relation to the learning objectives to be achieved.

The creation of international chemical education centres.(18)

A system involving a major centre with films, books, computers, consultants, etc., and regional centres tied to the major centre organizationally has been proposed. It is clear to all that problems of finance are far from being trivial here. A wonderful system is easy to contemplate, but almost impossible to finance.

Significant reports

A number of topics are of concern to chemists, but reliable information is limited. Preparation of authoritative reports might well be appropriate. Suggested areas include: (a) utilization of chemists at all levels; (b) the training and retraining of teachers (local reports including local problems and pressure points would be needed; large philosophical reports have been prepared already); (c) interactions with other disciplines in a search for areas of mutual concern; (d) technician training; (e) chemical education in Europe; (f) chemical education in developing countries. This list is illustrative, not exhaustive.

Programmes of teacher exchange and student exchange

It is clear that the problem is financial and organizational not philosophical.

Programmes to complete the training of students

This is particularly appropriate for students returning to non-industrialized countries and for some students going into industry, etc. It has been suggested that industrial internships and courses in applied science might be formulated. The difference between the courses in applied science and related engineering disciplines would have to be specified. Perhaps joint academic-industrial panels should be created.

SUMMARY

International collaboration in the teaching of chemistry exists at a very healthy level. While some problems and pitfalls must be recognized, there has been substantial progress toward making chemistry a bridge between nations and cultures. Where problems have appeared, the best efforts of chemists and government officials could minimize the impact of these problems on society. Such remedial action is strongly urged. International cooperation in chemical education thrives on communication between educators.

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1. Recommendations

As explained in the Preface, the preceding 13 chapters on different trends and problems of chemistry education served, in draft form, as a basis of discussion for 13 working groups at the International Congress on the Improvement of Chemistry Education in Wroclaw, Poland, in September 1973. These same working groups were charged with formulating recommendations for action to be taken in the light of the existing trends and problems. Some of the authors of the trend papers have incorporated in the final versions certain of these recommendations.

In addition to this, at the Congress itself, all action recommendations from all working groups were assembled in draft form for review and discussion at the final plenary session. No formal votes were taken on the exact wording of any or all of the recommendations. However, all participants in the Congress were given an opportunity to make any comments or suggestions they wished and an effort has been made by the Rapporteur to accommodate the essence of such interventions in putting the recommendations in their final form as below. The recommendations are grouped first of all according to the audiences for which they are intended (international organizations and agencies, national groups and organizations, and individual institutions and universities) and secondly according to the type of action to be taken (survey, publications, design and testing of new methods and materials, research, etc.) Throughout the set of recommendations, wherever the problem or phenomenon involved is not unique to chemistry education but applies in some way to other areas of science education (the learning process, trends in student characteristics, etc.), it is to be understood that the participants in the Congress recommended to their fellow chemistry educators around the world that action should be undertaken in concert with colleagues in other scientific disciplines.

A. INTERNATIONAL ORGANIZATIONS AND AGENCIES

1. Structures for international exchange of ideas and information

(a) Efforts should be made to strengthen the links among all groups active in the improvement of chemistry education in order to form an effective international network for the acquisition and dissemination of relevant ideas and information.

(b) Unesco's Science and Technology Education Information Centre should increase its holdings, activities, and resources in the area of chemistry education.

(c) The IUPAC Committee on the Teaching of Chemistry should not only make increased use of its national representatives for purposes of information exchange but should also foster unofficial contacts with groups in other countries and with Unesco field experts in chemistry education.

2. Surveys and studies

(a) In order to ascertain what psychological generalizations may apply, a study should be made of the instructional practices associated with the various major curriculum projects in the area of chemistry education.

(b) Data on those student characterstics that have greatest relevance to the learning process should be collected internationally.

(c) A survey should be made on the unique trends and problems of chemistry education in developing countries.

(d) A global study should be undertaken, over a period of at least five years, to determine the needs of chemistry teachers and to evaluate the national possibilities of responding to these in the light of economic conditions and the availability of international assistance.

(e) A survey on chemical education at the tertiary level in Europe should be undertaken.

(f) On an international basis, comparable statistical data should be gathered on the output of chemists with varying amounts of university training, on the availability of industrial posts for chemists, and on the utilization of chemists at all levels.

(g) For purposes of improved teaching, an analysis should be made of the relations among chemical concepts and of the conceptual structure underlying chemical knowledge.

(h) An analysis should be made of the applicability of knowledge and theories of educational psychology to chemistry education at the different levels.

3. Research

(a) Experiments should be undertaken to determine the effect upon the achievement of chemistry students of increased precision in the specification of learning objectives.

(b) Encouragement should be given to multinational experiments on the psychological aspects of the teaching and learning of chemistry.

(c) Research should be continued on the relationship between various nutritional factors and brain functioning.

4. Publications

(a) The IUPAC Committee on the Teaching of Chemistry should implement its plan to issue regularly an international newsletter on chemistry education improvement.

(b) To provide a forum for ideas on issues and problems of chemistry education which affect many countries, the feasibility of establishing an international journal of chemical education should be examined.

(c) On a periodic basis, the most outstanding articles and other materials should be selected from the world literature on chemistry education and the composite should be published as an anthology.

(d) For purposes of international reference, a publication should be issued which fully documents the procedures used by the various major projects in their development of chemistry curricula, teaching materials, etc.

(e) Articles on the training and retraining of chemistry teachers at all levels should be commissioned by Unesco and published.

(f) A publication should be commissioned which brings together literature on various aspects of the effects of chemicals on behaviour (e.g. pheromones, mosaics, circadian rhythms, and brain chemistry).

(g) Two years after the publication of these recommendations, a report should be published on progress in their implementation.

5. Meetings and conferences

(a) At intervals of approximately every four to five years, a congress of the type convened in Poland in September 1973 should be held for purposes of making an overall review of trends and problems in chemistry education (all forms, levels, and aspects) and of formulating a plan of international cooperative action for further improving chemistry education.

(b) As follow-up of and/or as preparation for international congresses such as just mentioned above, regional meetings should be convened to examine common problems and to promote regional cooperation in their solution.

(c) Also as a follow-up of the periodic congresses which examine all aspects of chemistry education, meetings and symposia should be convened (regionally or internationally) on specific topics which require more detailed and sustained attention; two specific suggestions of this type are: a workshop to help teachers understand better how to formulate the aims and objectives of chemistry courses and to translate such aims into meaningful action in various learning situations (classroom, laboratory, etc.); and a symposium which would analyse and prepare a report on experience in the use of educational technology in the teaching of chemistry.

6. Design and evaluation of new programmes, materials and methods

(a) Regional centres, such as RECSAM (Regional Centre for Education in Science and Mathematics) in Malaysia, should be established for the purposes of developing and testing new methods and materials for the teaching of chemistry and of disseminating the results regionally and internationally.

(b) Competitive grants should be made available internationally and nationally to finance experiments in the design of core courses and optional courses that better reflect the changing nature of the structure of chemistry.

(c) An international centre for educational technology in chemistry education should be established for the dissemination of information, for the training of teachers, and for the development of teaching materials, especially in relation to conditions in developing countries.

7. Advisory services

To better enable international organizations to respond to requests from countries or individual institutions for advice in specific aspects of chemistry education, lists should be prepared of experts who are qualified to render advice in the following areas:

(a) Testing and examination procedures, the content of examinations in relation to stated objectives, the selection of instruments of assessment from among those currently available, and the development on new or improved instruments of assessment.

(b) All aspects of the organization and administration of chemistry education at the university level, including the development and evaluation of educational structures compatible with objectives, resources, and other relevant factors.

(c) Correlation of academic qualifications and standards (e.g., the work of the International Baccalaureate and the plans of the Federation of European Chemical Societies).

(d) The selection and/or adaptation of educational techniques and equipment in the light of objectives, resources, etc.

(e) The continuing education of chemists and chemistry teachers.

8. General

(a) Exchange of students and teachers of chemistry among nations should be fostered by whatever international or national means are available.

(b) Unesco should examine ways of minimizing the problem of educational software such as films, slides, etc.

B. NATIONAL GROUPS AND ORGANIZATIONS

1. Structures for the improvement of chemistry education

(a) In countries where they do not already exist, some national mechanism appropriate to the conditions of the country (e.g. chemistry teachers' organization, or education committee of a chemical society) should be established as a way of allowing all interested individuals to associate themselves with efforts (such as those which follow) to improve chemistry education.

(b) Where they do not exist, national centres (usually attached to an educational institution or ministry) should be established to provide an institutional framework for efforts to improve chemistry education, such centres being encouraged also to play a role at the international level.

2. Surveys and studies

(a) Studies should be made of the different methods of training and retraining, through universities and colleges of education, chemistry teachers for the various levels.

(b) The results of the use of satellites for chemistry education (for both students and the general public) should be studied.

(c) National lists should be prepared of individuals active in the improvement of chemistry education, such lists to be used for both internal and international exchange of ideas and information.

(d) National lists should be prepared, in appropriate languages, of books and articles on the improvement of chemistry education.

3. Research and development

(a) Assessments should be made of the effectiveness of new techniques in chemistry education (e.g. self-paced learning and open-ended laboratory instruction).

(b) Experiments should be undertaken on the use of educational technology in chemistry education (for both conventional courses and continuing education), perhaps within the framework of a national centre specializing in this field.

4. Publications

Monographs should be published on new techniques and methods of teaching chemistry.

5. Meetings

(a) Workshops and courses for chemistry teachers should be organized.

(b) National groups should cooperate with their counterparts in other countries in the organization of regional meetings on general or specific aspects of chemistry education.

6. General

(a) National groups should foster links between chemists and professional educators in order to achieve greater cooperation and understanding between these two groups (e.g. educators could periodically be involved in the work of university chemistry departments and scientists as well as administrators could be involved in the development of curriculum projects).

(b) The general subject of the mechanisms of change and innovation in chemistry education should be examined in various ways (e.g. articles, conferences, and comparative studies with other countries).

(c) Mechanisms should be created for liaison and cooperation with colleagues in other sciences to facilitate a joint attack on common problems (e.g. the training and retraining of teachers, the use of educational technology, low-cost instructional equipment).

(d) National groups should urge those responsible for budgetary allocations to provide funds for educational research and development (about 5 per cent of the operating budget being a desirable figure) and the involvement of chemists in such research and development should be accorded a status equal to that of other professional activities.

C. INDIVIDUAL INSTITUTIONS AND UNIVERSITIES

1. Chemistry should play a significant part in general education and in education for citizenship and should not be just a discipline for the instruction and training of chemists.
2. Precise statements of the objectives of chemistry courses should be made, and these should include objectives beyond those specifically concerned with factual knowledge and its immediate applications; these objectives should be known to teachers and students, and the assessment should reflect the objectives.
3. The chemistry curriculum at undergraduate level should consist of a 'core' course followed by a variety of 'package' courses in (a) the chemical area, (b) scientific non-chemical areas, and (c) non-scientific areas from which a student can choose a mixture for his graduation requirements to suit his personal abilities, interests and intentions; the 'core' course should be not less than one year in duration, should be at the professional level, should be more integrated with respect to subject matter than traditional courses, and should be designed and presented by the most effective and experienced teachers in a department.
4. Courses should be developed that are concerned with the larger and broader issues of chemistry, including integrated courses illustrating the relationship between natural sciences, technology, economics, the needs of society, and the social implications of science.
5. During the first two years of an undergraduate curriculum, 15-20 per cent of the time available should be devoted to non-scientific studies such as economics, socio-political studies, philosophy and literature.
6. Chemistry students should spend a period of at least three months in industry during their university studies (after basic studies and before special options).
7. The participation of undergraduate students in research programmes at an early stage should be encouraged.
8. The possibilities of introducing university students to school teaching, under supervision, should be explored.
9. The role that chemistry plays in industry should be clarified in order to inform students of the significance of industrial practices.
10. The opinions of students and young professionals about chemistry teaching and careers in chemistry should be obtained as an essential feedback in designing courses, and course objectives should include specific plans for influencing and changing behaviour of students.
11. Educational institutions should encourage the judicious use of new methods of teacher training, including various aspects of modern educational technology, in the teaching of chemistry.
12. The career structure of university chemistry teachers should give greater consideration to contributions to teaching and/or educational research and development.
13. Cooperation between industry and university and between universities should include exchange of personnel, internationally as well as within individual countries.

2. Members of working groups

As indicated in the Preface and Recommendations, the 13 chapters in this publication were put in final form by the respective authors after drafts of their papers had been discussed by 13 working groups at the International Congress on the Improvement of Chemical Education held in Poland in September 1973. In all cases, the authors have indicated a desire to acknowledge the many valuable contributions made by the members of their respective working groups. For that purpose, the following list gives the names and nationalities of those who, in addition to the authors, were members of the various groups.

The changing needs and views of society

W. B. Cook, chairman (U.S.A.)
A. W. Jeffrey (United Kingdom)
W. Lauterbach (German Democratic Republic)
F. Llanes (Cuba)
M. Minssen (Federal Republic of Germany)
F. Morsingh (Malaysia)
S. Paszyc (Poland)
L. Pechy (Hungary)

The evolving demands of industry and other professions

R. Guillaumont, chairman (France)
H. Boniecka (Poland)
N. Costanedo (Cuba)
R. Eisele (Federal Republic of Germany)
E. Grzywa (Poland)
P. Kepinski (Poland)
A. Lodes (Czechoslovakia)
D. Mikuteit (German Democratic Republic)
D. Odhiambo (Kenya)
S. Shakshouki (Libya)

The evolution in the nature and structure of chemistry

P. Sykes, chairman (United Kingdom)
S. Bank (U.S.A.)
B. Baranowski (Poland)
J. Bruhn (Denmark)
A. A. Caretto, jr., (U.S.A.)
L. Friss (Argentina)
W. Hornix (Netherlands)
J. Kovác (Czechoslovakia)
A. Piatkiewicz (Poland)
L. Sobczyk (Poland)
L. C. de Torre (Argentina)

The changing characteristics of students

G. Aylward, chairman (Australia)
L. Brossard Perez (Cuba)
R. Halasi (Yugoslavia)
E. Hoyer (German Democratic Republic)
M. Lafitte (France)
T. M. Poole (United Kingdom)
H. Sadek (Arab Republic of Egypt)
H. Sastre (Argentina)
M. Wrońska (Poland)

Up-to-date and more precise learning objectives in chemistry

A. Bielański, chairman (Poland)
A. Bak (Denmark)
S. Davies (Canada)
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